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HIGH-SPEED RESEARCH WORKSHOP, PART
1 (NASA. Langley Research Center)
482 p

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*NASA Conference Publication 10087
Part 1*

First Annual High-Speed Research Workshop

*Compiled by
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Langley Research Center
Hampton, Virginia*

Proceedings of a workshop sponsored by the
National Aeronautics and Space Administration,
Washington, D.C., and held in
Williamsburg, Virginia
May 14-16, 1991

APRIL 1992

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NASA

National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23665-5225

FOREWORD

The First Annual High-Speed Research (HSR) Workshop was hosted by NASA Langley Research Center and was held May 14-16, 1991, in Williamsburg, Virginia. The purpose of the workshop was to provide a national forum for the government, industry and university participants in the program to present and discuss important technology issues related to the development of a commercially viable, environmentally compatible U.S. High-Speed Civil Transport. The workshop sessions and this publication are organized around the major task elements in NASA's Phase I - High-Speed Research Program which basically addresses the environmental issues of atmospheric emissions, community noise and sonic boom.

The opening Plenary Session provided program overviews and summaries by senior management from NASA and industry. The remaining twelve technical sessions were organized to preview the content of each program element, to discuss planned activities and to highlight recent accomplishments.

Attendance at the workshop was by invitation only and included only industry, academic and government participants who were actively involved in the High-Speed Research Program. The technology presented at the meeting is considered commercially sensitive, and as such, the conference results and this publication are protected by the NASA designation **LIMITED DISTRIBUTION**.

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Session I. Plenary Session

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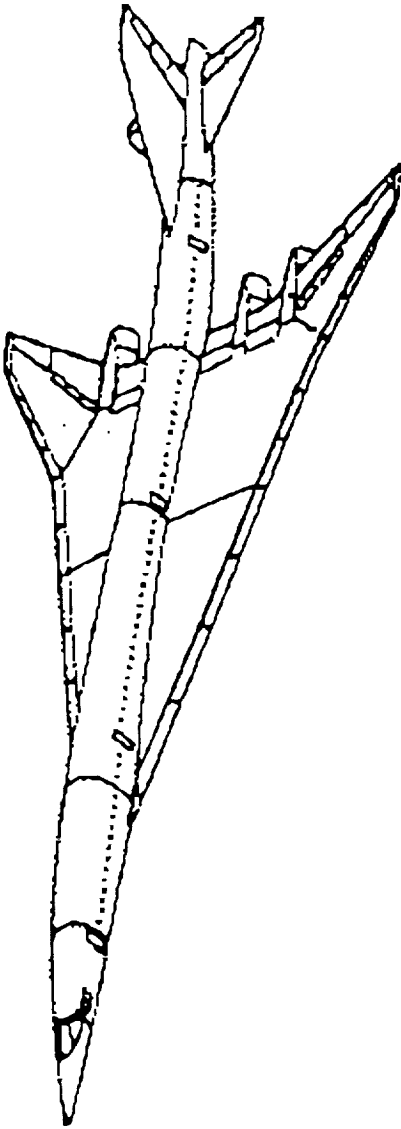
Session I. Plenary Session

Headquarters Perspective

Robert E. Anderson, NASA Headquarters, Code RJ

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NASA
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First Annual HSR Program Workshop

Headquarters Perspective

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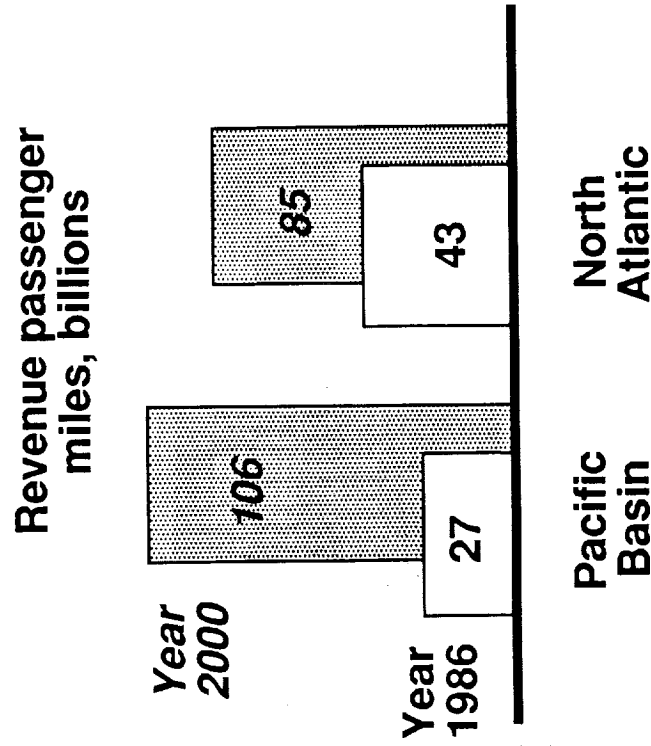
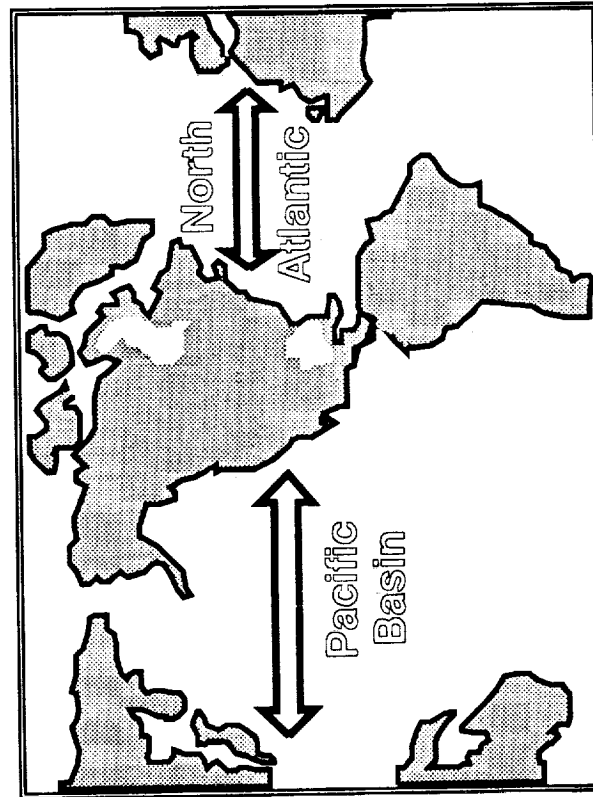
Office of
Aeronautics
Exploration and
Technology

Robert E. Anderson
Assistant Director for Aeronautics

OVERVIEW

- NATIONAL CHALLENGE
- PROGRAM GENESIS & STRUCTURE
- WORKSHOP OBJECTIVES

HIGH-SPEED TRANSPORT MARKET



300,000 HSCT passengers per day possible in year 2000

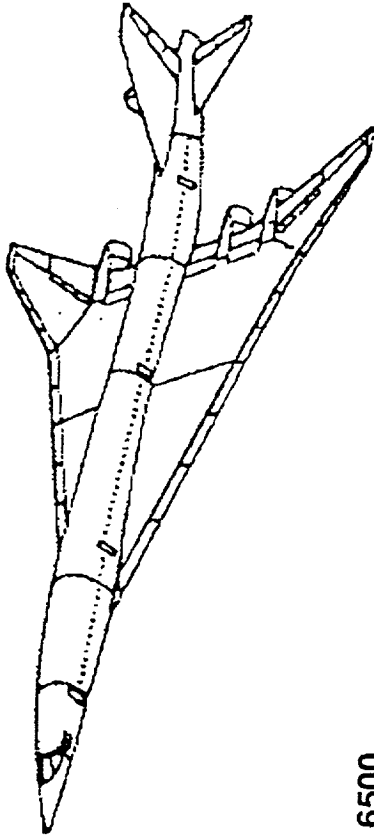
Supersonic Transport Challenge

Keys to Success

- Environmentally acceptable
- Technically feasible
- Economically viable

Goals

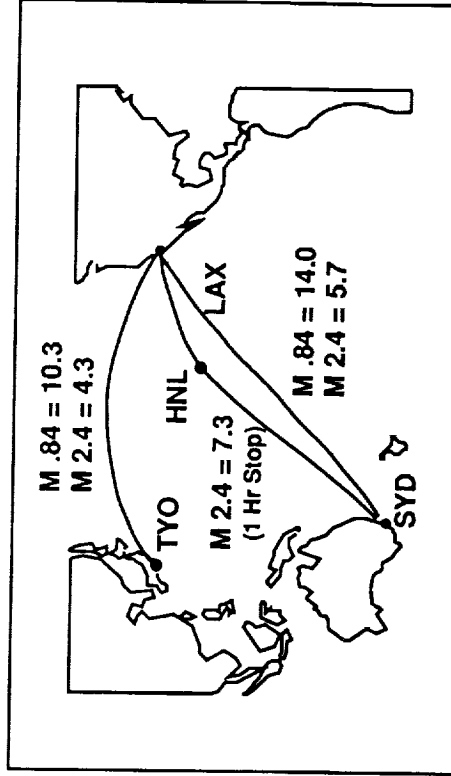
- Introduction: 2005
- Speed: Mach 2.4
- 250-300 passengers
- Range: 5000 nautical miles; growth to 6500
- Fare level: near current market



Comparative Perspective

	Concorde	U.S. SST	HSCT
Market	North Atlantic	North Atlantic	Atlantic and Pacific
Range (nmi)	3000	3000	5000-6500
Payload (pass)	103	200	250-300
TOGW (lb)	400,000	650,000	700,000
Community Noise standard	(waiver)	Stage 2	Stage 3
foot print (sq mi)	75	50	5-6
Revenue req'd (cents/RPM)	87	60+	10 (goal)

Example Trip Times Hours



NATIONAL CHALLENGE

- Long distance air travel is a large and rapidly growing market
- HSCT represents the next plateau in an aggressive international aviation competition
- Major technological uncertainties remain, acting as barriers to successful HSCT introduction
- NASA has a strong capability, and a critical national role, in the high-speed arena

**NASA'S AERONAUTICS R&T
CORNERSTONE FOR THE 1990'S**



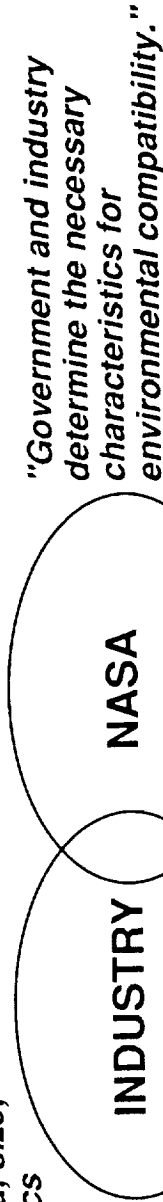
Agenda for Achievement

Action Plan Recommendations

"Industry provide strong, creative leadership. A high-speed transport will probably require pooled resources..."

"Industry and NASA determine the most attractive technical concepts and the necessary technology developments..."

"Industry analyze the market needs for an advanced high-speed transport and identify the economic, speed, size, range and fuel characteristics necessary..."



"Government and industry determine the necessary characteristics for environmental compatibility."

"NASA, industry and academia begin a focussed and coordinated approach to ready required technology for U.S. industry development and application."

Develop fundamental technology, design, and business foundation for a long-range, supersonic transport in preparation for a U.S. industry initiative.

CIVIL AERONAUTICS

TECHNOLOGY DEVELOPMENT AND VALIDATION PLAN



Office of
Aeronautics and
Space
Technology

MARCH 1988

RJ88-383(1)

CIVIL AERONAUTICS TECHNOLOGY DEVELOPMENT & VALIDATION PLAN

"NASA IS DIRECTED TO PREPARE A MULTI-YEAR TECHNOLOGY DEVELOPMENT VALIDATION PLAN THAT WILL HELP THE UNITED STATES RETAIN ITS LEADERSHIP IN AERONAUTICS RESEARCH AND TECHNOLOGY AND COMPETE IN THE INTERNATIONAL MARKETPLACE FOR FUTURE CIVIL AIRCRAFT. THIS PLAN SHALL BE PREPARED IN COOPERATION WITH PRIVATE INDUSTRY AND SHALL BE DESIGNED TO ASSURE CONTINUED U.S. LEADERSHIP IN FUTURE CIVIL AIRCRAFT MARKETS. THIS PLAN SHOULD BE SUBMITTED TO THE COMMITTEE BY MARCH 1, 1988."

NASA AUTHORIZATION ACT, 1988

**SENATE COMMITTEE ON COMMERCE,
SCIENCE AND TRANSPORTATION**

JUNE 24, 1987

AERONAUTICS STRATEGIC THRUSTS

OAET

- **SUBSONIC AIRCRAFT/NATIONAL AIRSPACE**

Develop selected, high-leverage technologies and explore new means to ensure the competitiveness of U.S. subsonic aircraft and to enhance the safety and productivity of the National Aviation System

- **HIGH-SPEED AIR TRANSPORTATION**

Resolve the critical environmental issues and establish the technology foundation for economical, high-speed air transportation

- **HIGH-PERFORMANCE MILITARY AIRCRAFT**

Ready technology options for revolutionary new capabilities in future high performance fixed and rotary wing aircraft

- **HYPERSONIC/TRANSATMOSPHERIC VEHICLES**

Develop critical technologies to support ground and flight demonstration of the X-30 National Aero-Space Plane and the development of future hypersonic vehicles

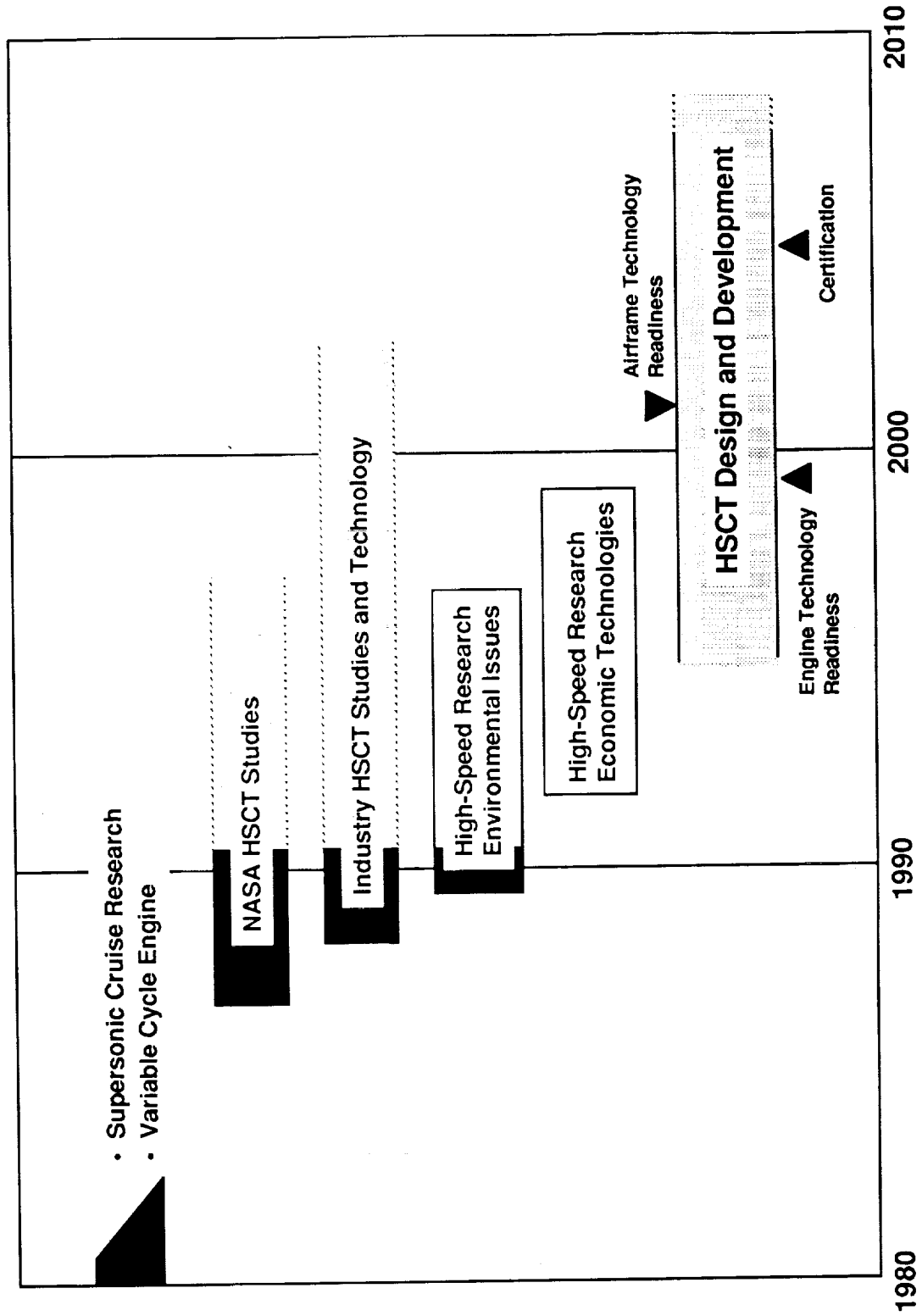
- **CRITICAL DISCIPLINES**

Pioneer fundamental research, cross-cutting technology development, and validation of numerical simulation techniques to maintain the theoretical, experimental, and predictive foundation required for the design and operation of advanced aerospace systems

- **NATIONAL FACILITIES**

Develop, maintain, and operate critical national facilities for aeronautical research and for support of industry, DoD, and other NASA programs

SECOND GENERATION HSCT APPROACH

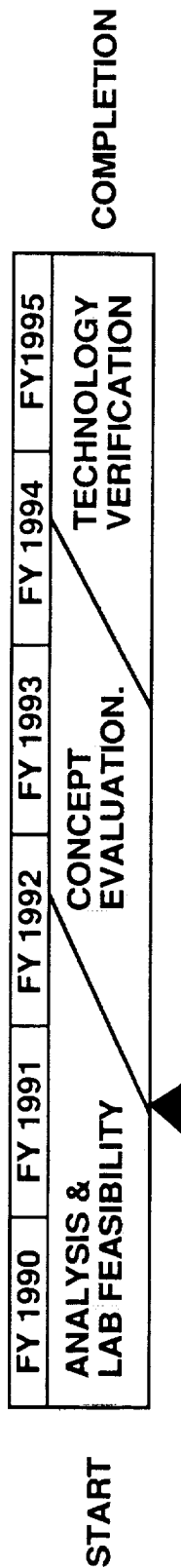


HIGH-SPEED AIR TRANSPORTATION

Resolve the critical environmental issues and establish the technology foundation for economical, high-speed air transportation

- **BY 1995, RESOLVE THE ENVIRONMENTAL ISSUES OF ATMOSPHERIC IMPACT, AIRPORT NOISE AND SONIC BOOM**
 - Develop low-emission combustor technology & atmospheric models leading to acceptable fleet impact assessments
 - Develop source noise reduction, high-lift technologies and operational procedures leading to aircraft noise impact consistent with FAR 36 - Stage 3
 - Develop low-boom aircraft configurations and define viability of supersonic over-land flight

PHASE I EARLY RESULTS



EMISSIONS

PROMISING ATMOSPHERIC MODEL RESULTS INDICATING
POTENTIAL ACCEPTABILITY OF TARGET EMISSION LEVELS

- Less than 1% ozone depletion for mature HSCT fleet

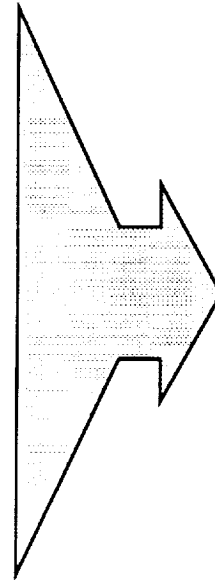
FLAME TUBE NOx FORMATION AND CONTROL DEMONSTRATION

- < 5 grams / Kg NOx measured under simulated operating conditions

NOISE

SCALE-MODEL NOZZLE ACOUSTICS DEMONSTRATION

- > 15 EPNdB measured noise reduction



READINESS FOR INITIATION OF PHASE II TECHNOLOGY DEVELOPMENT PROGRAM

HIGH-SPEED AIR TRANSPORTATION

Resolve the critical environmental issues and establish the technology foundation for economical, high-speed air transportation

- BY 1998, DEVELOP AND VERIFY, IN COOPERATION WITH U.S. INDUSTRY, THE HIGH-LEVERAGE TECHNOLOGIES ESSENTIAL FOR ECONOMIC VIABILITY
 - Develop enabling propulsion materials & critical adv. propulsion components, and demonstrate their integration in technology test beds
 - Develop advanced wing aerodynamic configurations providing increased transonic & supersonic L/D, and demonstrate low-speed, high-lift system & propulsion system integration
 - Develop light-weight, high-temperature airframe materials & structural concepts, and demonstrate large component fabrication & durability
 - Develop & demonstrate integrated controls & low-visibility flight deck technologies critical to efficient international airspace system operation
 - *Assess airframe, propulsion and flight deck technologies for their impact on high-speed civil transport environmental acceptance and economic viability*

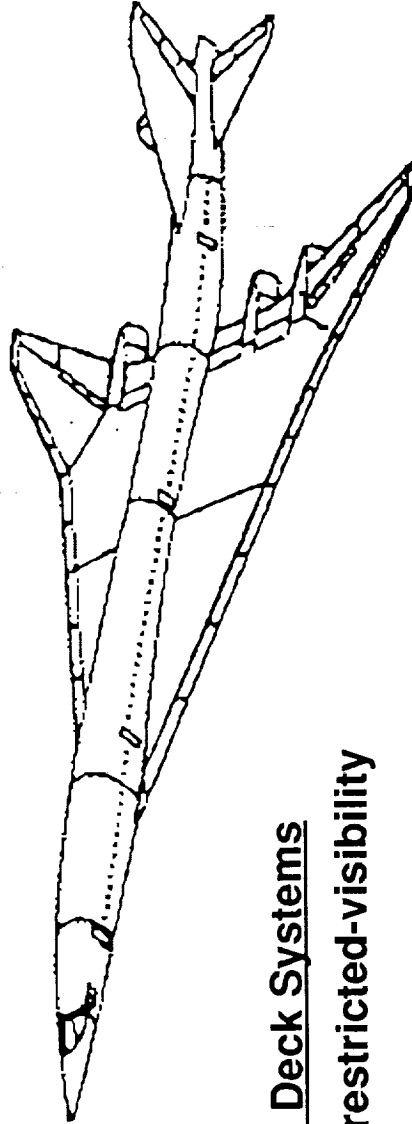
HIGH-SPEED RESEARCH PHASE II

Airframe

- Airframe materials & structures technology
- Aerodynamic performance & integration

Propulsion

- Critical propulsion components
- *Enabling Propulsion Materials*
- Propulsion system demonstration



Flight Deck Systems

- Advanced, restricted-visibility cockpit

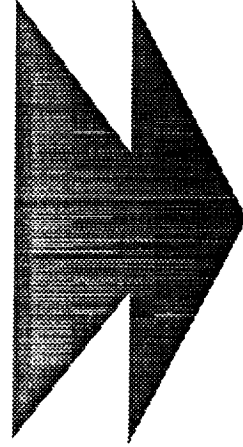
HSR PROGRAM PRIORITY

A SUCCESSFUL SST WILL PERMIT LITTLE ROOM

FOR DESIGN COMPROMISES

"Past experience indicates that there will be little room for design compromises in the development of a successful SST. To meet the stringent environmental constraints of noise, sonic boom, and pollution in a safe, economically competitive SST will require the best possible combination of aerodynamic, structural, and propulsion technologies. Isolated advances in the disciplinary technologies are meaningless unless they can be integrated into a congruent airplane that meets all mission requirements."

F. EDWARD MCLEAN, "SUPERSONIC CRUISE TECHNOLOGY,": NASA SP-472, 1985, P. 6



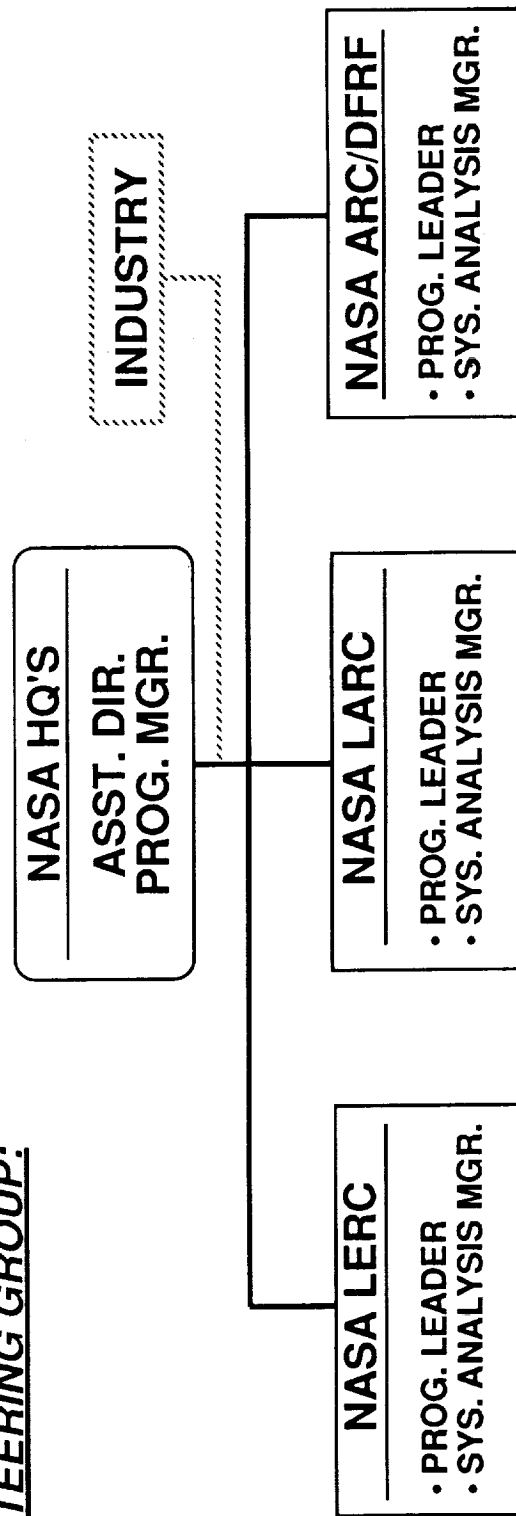
***AN INTEGRATED NATIONAL TECHNOLOGY PLAN
IS CRITICAL TO SUCCESS***

INTEGRATED NASA/INDUSTRY HSR PLAN

OBJECTIVE:

- ESTABLISH UNIFIED FRAMEWORK BETWEEN NASA AND INDUSTRY FOR COORDINATED PURSUIT OF HSCT DEVELOPMENT
 - Develop technology priorities, critical path and schedules
 - Enhance communication between performing organizations (NASA, industry & academia)
 - Assess progress in discipline areas from system perspective to ensure high-payoff & timely technology deliverables

STEERING GROUP:



NASA AERONAUTICS R&D BUDGET

(\$,M)

	<u>1992</u>	<u>1993</u>	<u>1994</u>	<u>1995</u>	<u>1996</u>	<u>1997</u>
CONGRESSIONAL	<u>591.2</u>	<u>670.5</u>	<u>716.0</u>	<u>742.6</u>	<u>672.2</u>	<u>687.9</u>
SUBMITTAL (FY 1992)						

<u>HSR PHASE I</u>	<u>(76.4)</u>	<u>(89.9)</u>	<u>(90.4)</u>	<u>(70.9)</u>	<u>(11.0)</u>	-
Environmental	(59.9)	(57.9)	(49.9)	(46.9)	(-0.-)	
Enabling Prop. Mat'ls	(16.5)	(32.0)	(40.5)	(24.0)	(11.0)	(-0.-)

<u>HSR PHASE II</u>	?	?	?	?	?	?
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WORKSHOP OBJECTIVES

- **COMMUNICATE OBJECTIVES AND PROGRESS TO ALL PROGRAM PARTICIPANTS**
- **REVIEW AND DISCUSS FUTURE EFFORTS AND PLANS**

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Session I. Plenary Session

Boeing HSCT Program Summary

Michael L. Henderson, Boeing Commercial Airplane Group

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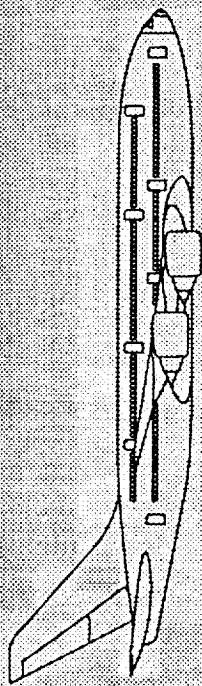
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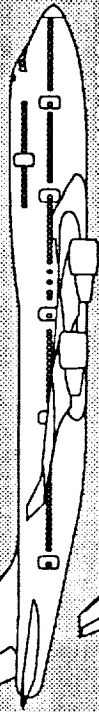
NASA Annual HSR Workshop Boeing HSCT Program Summary

M. L. Henderson

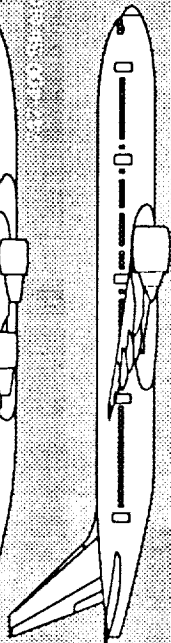
Boeing Commercial Airplane Group May 14, 1991



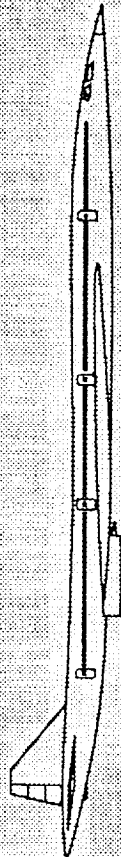
33499 - 33499



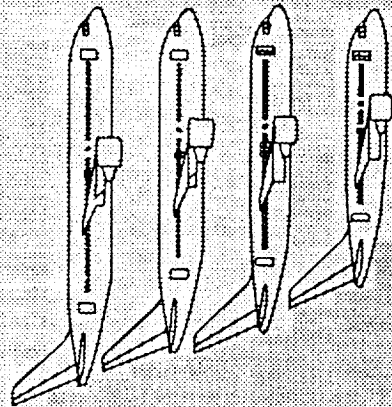
33499 - 33499



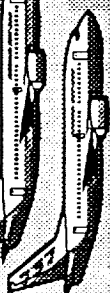
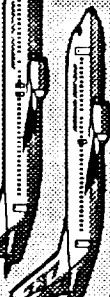
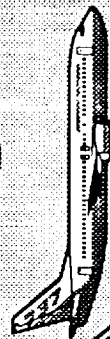
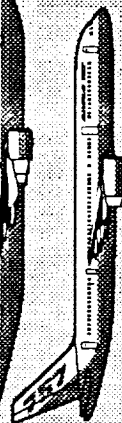
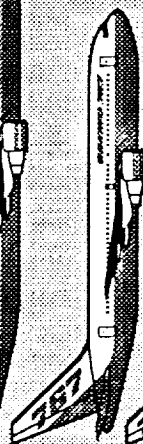
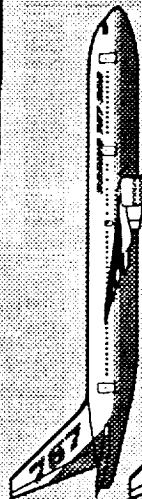
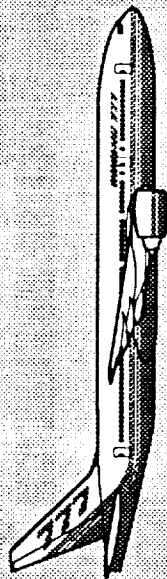
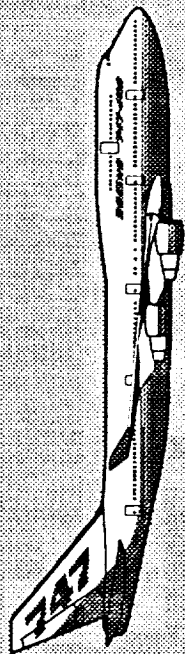
33499 - 33499



33499 - 33499



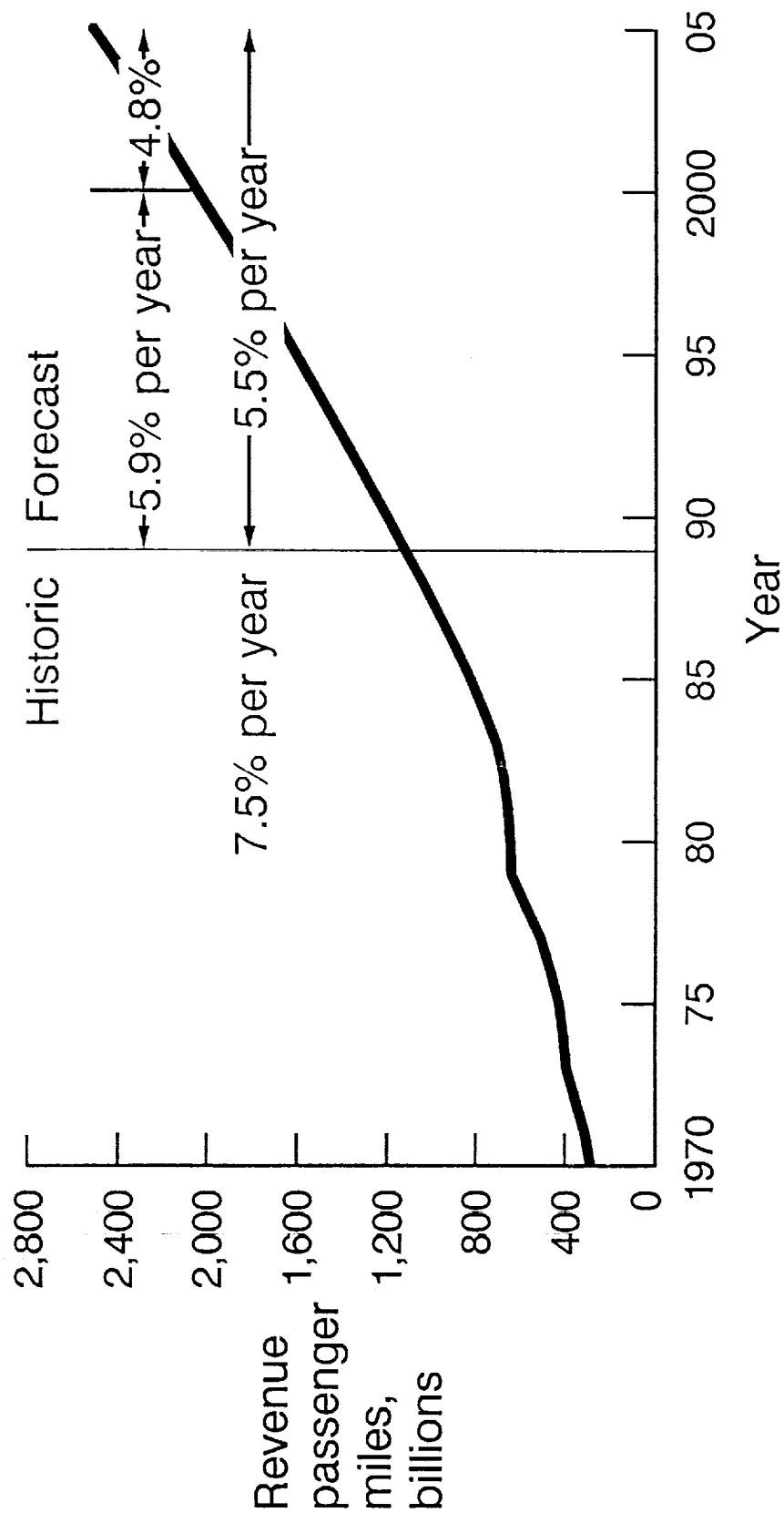
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Why Are We Looking At An HSCT Now?

- The forecast for long range scheduled international traffic is sufficiently large in the post year-2005 time period to support a fleet of HSCT's
- Technologies are projected to be available to create an HSCT that will have the required performance and operating economics, and which can be sold at a price that will provide a reasonable return to Boeing and the airlines.
- With relatively modest surcharges over competing subsonic fares, it is expected that an HSCT providing roughly a 50% time savings would capture a significant market share.
 - Passengers appear to be willing to pay...but how much?
 - Potential for stimulation of travel.
- Boeing cannot afford to pass on this potential market opportunity... we must continue to do our homework.

World Air Travel Forecast Through 2005

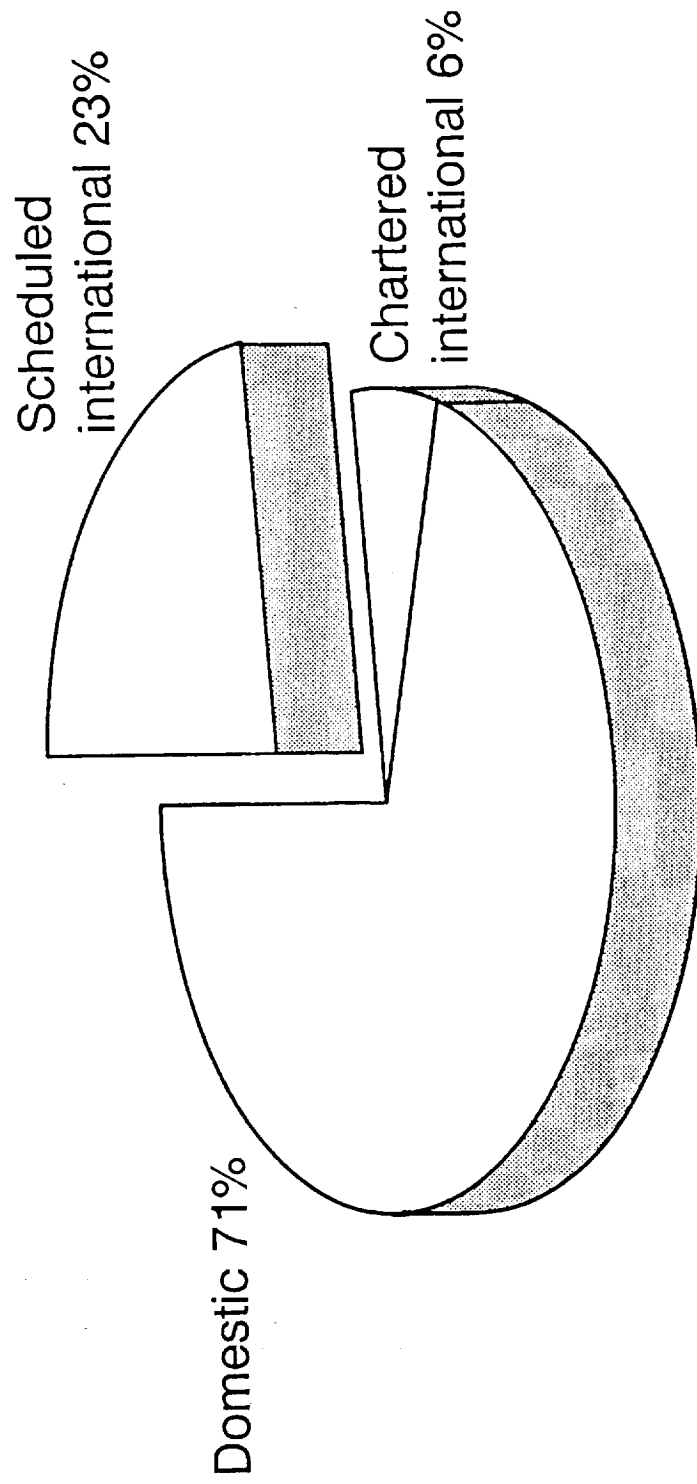


Note: Excludes U.S.S.R.

World Traffic Demand Forecast

Year 2000

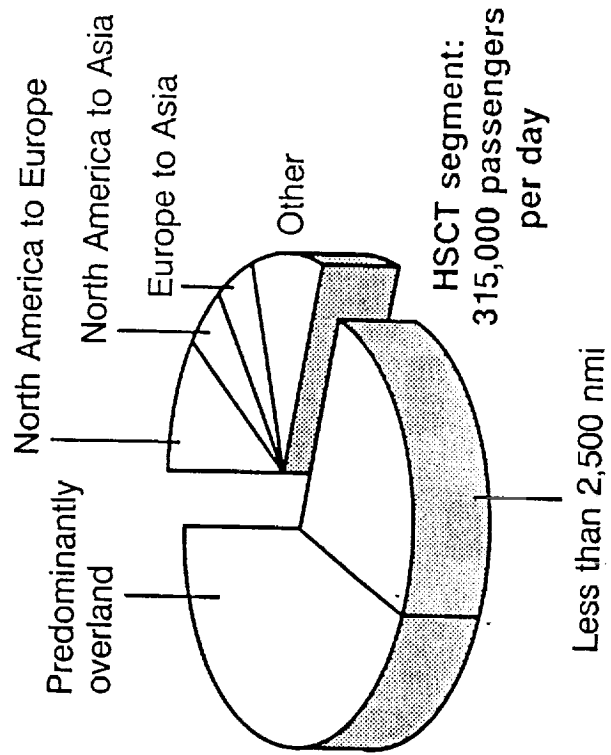
4.8 million passengers per day



HSCT Study Markets

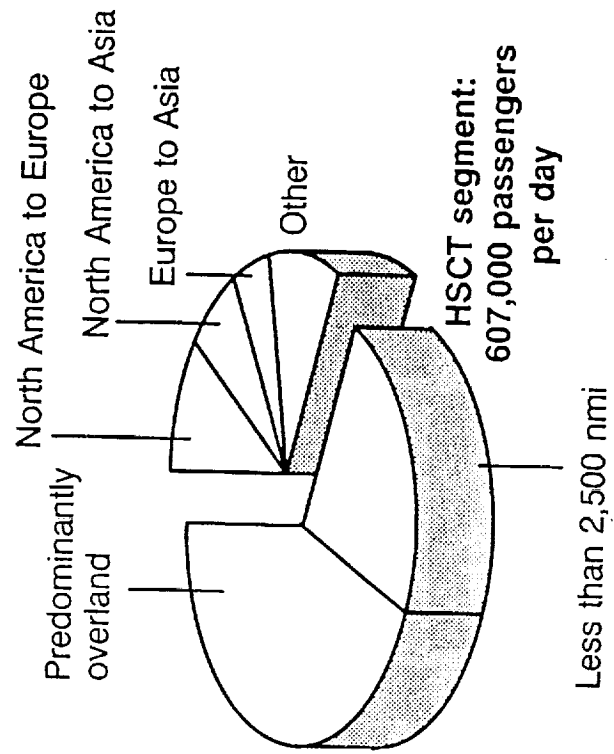
Year 2000

1.09 million passengers per day

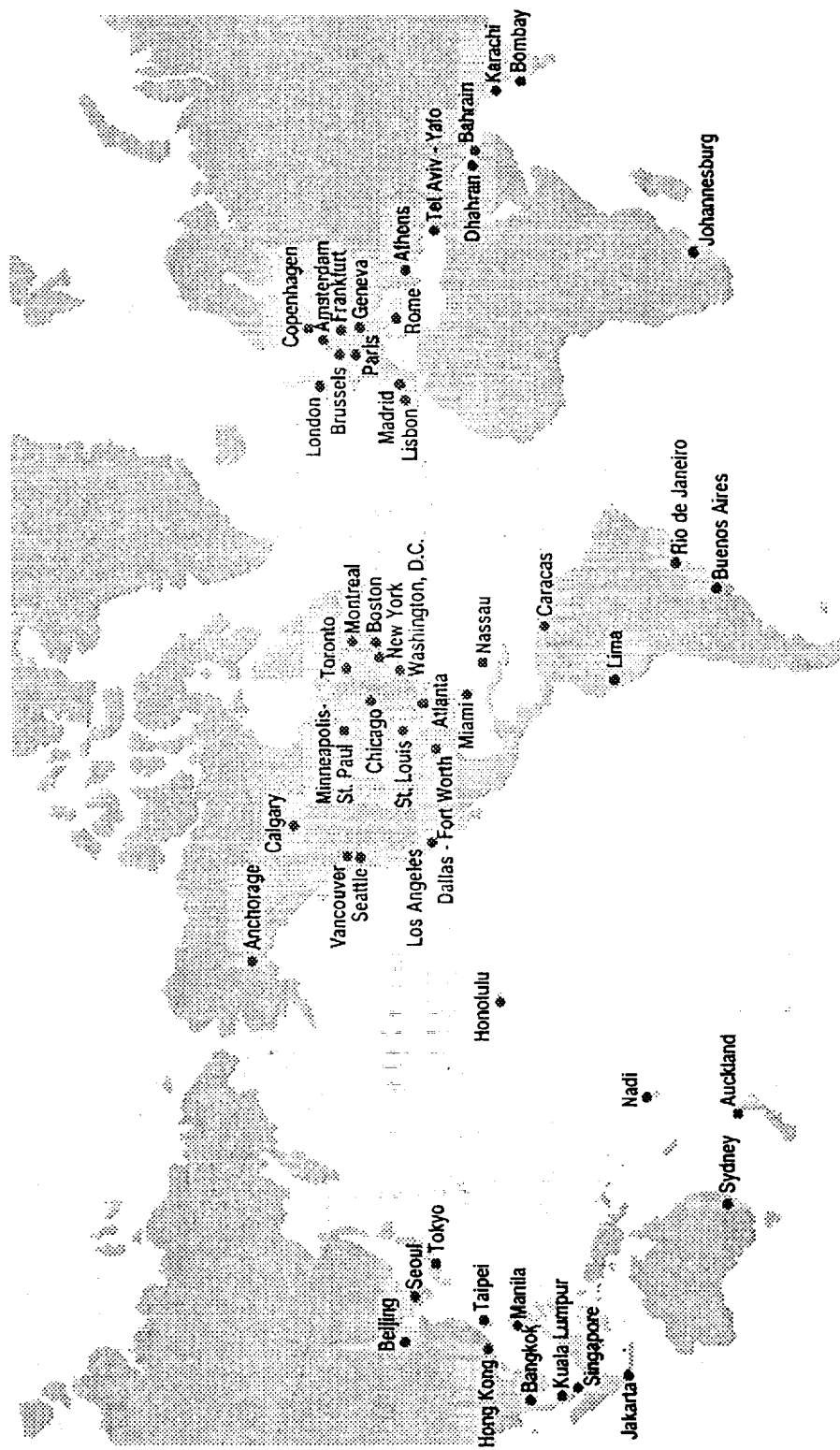


Year 2015

1.90 million passengers per day

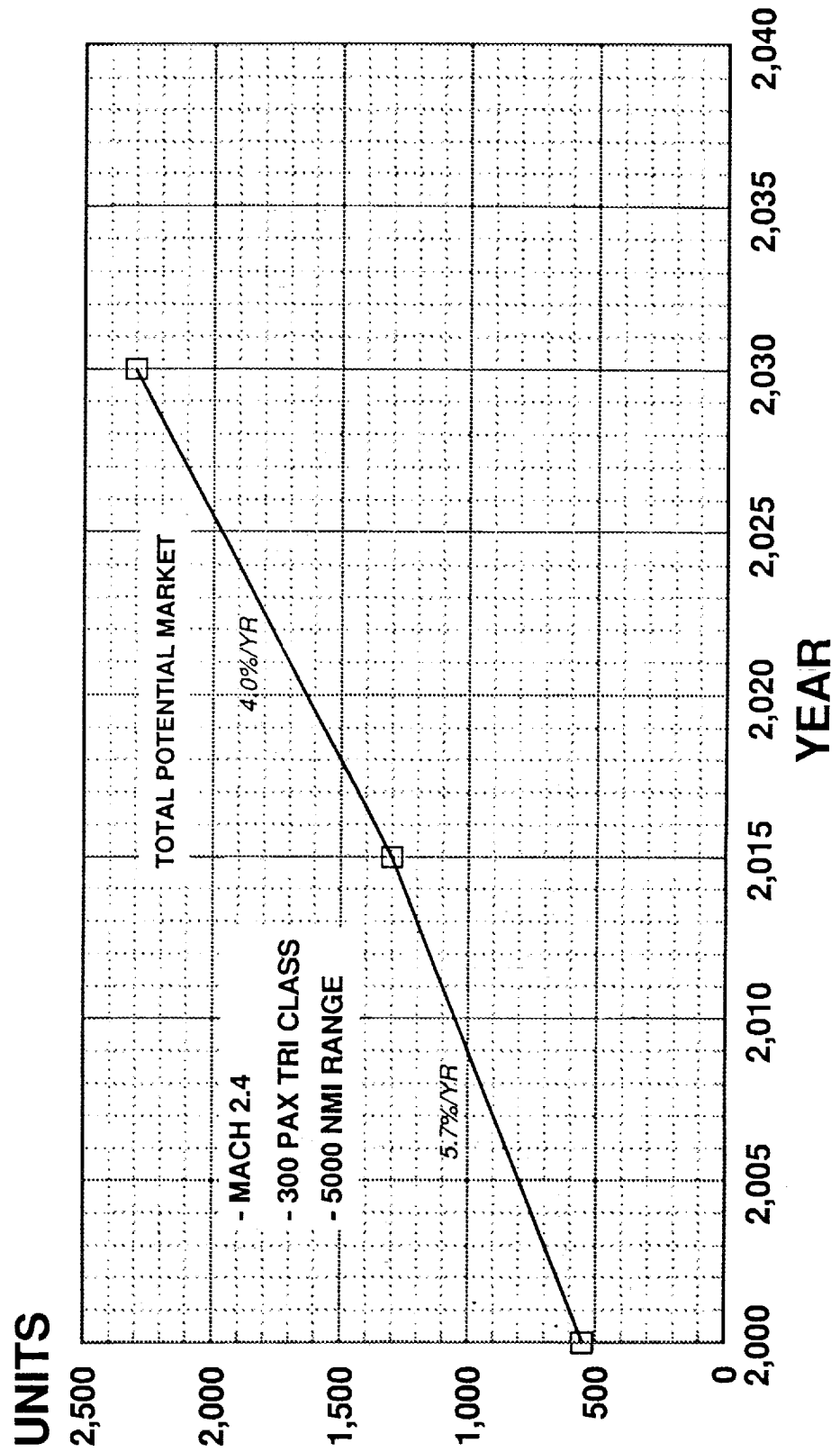


Cities Used in the Study Route System



HSCT MARKET ESTIMATE

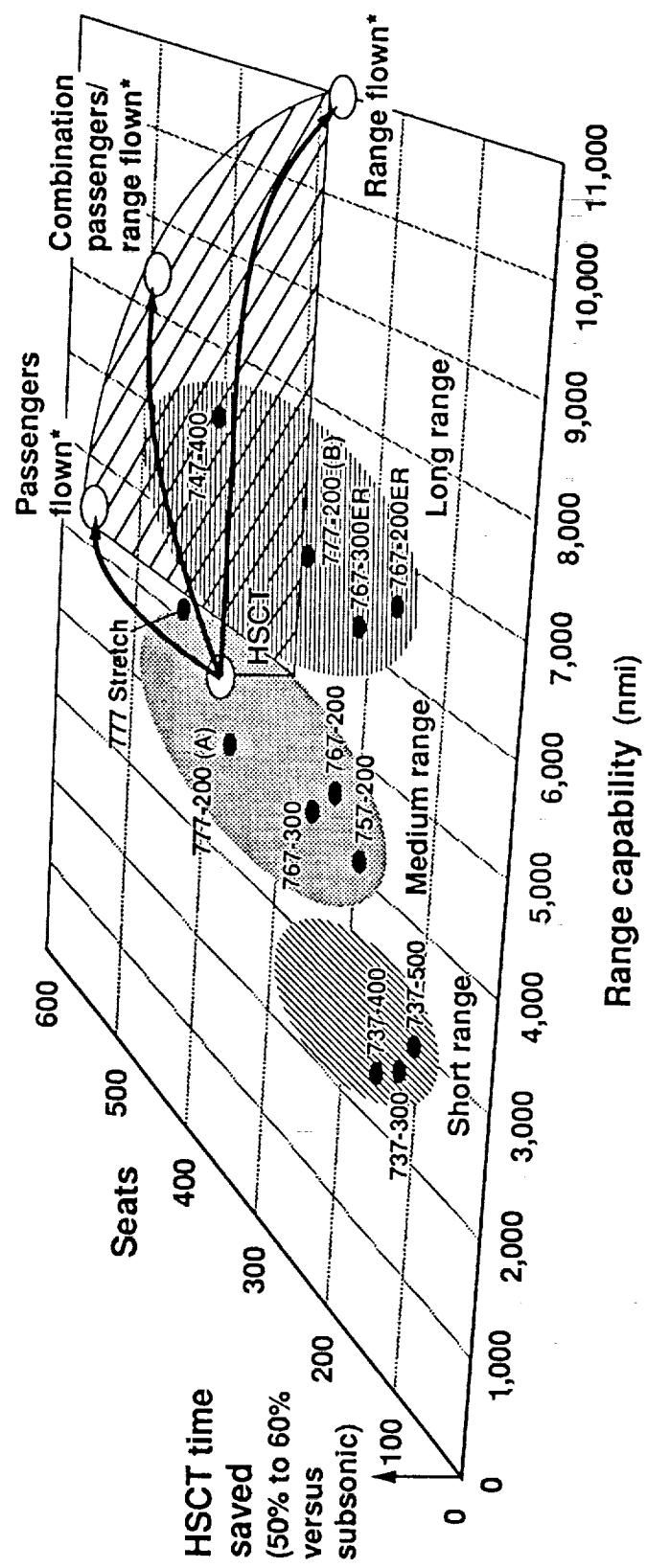
TOTAL POTENTIAL MARKET



Market Requirements

- **Speed**
 - Mach 2.4 provides a good balance in trip time benefit, technology risk, reducing environmental impact, and overall system scheduling efficiency.
- **Design range**
 - The initial range capability of 5000 nmi would provide non-stop service for city-pairs comprising approximately 80% of the forecast long range international scheduled passengers flown.
 - The airplane is projected to grow to 6,500 nmi range capability, expanding non-stop capabilities.
- **Seat-size**
 - The airplane is nominally 300 seats tri-class. This capacity provides a balance between reduced seat-mile costs and a size that is consistent with the increased frequencies of the HSCT.

HST Flexibility



* For equivalent subsonic trip time

Viable High Speed Civil Transport

Elements of success:

- Environmental acceptability
- Technical feasibility
- Economic viability

Environmental Goals

- Emissions:
 - No significant ozone depletion
- Airport noise:
 - As quiet as Stage III subsonic airplanes
- Sonic boom:
 - No perceptible boom over populated areas

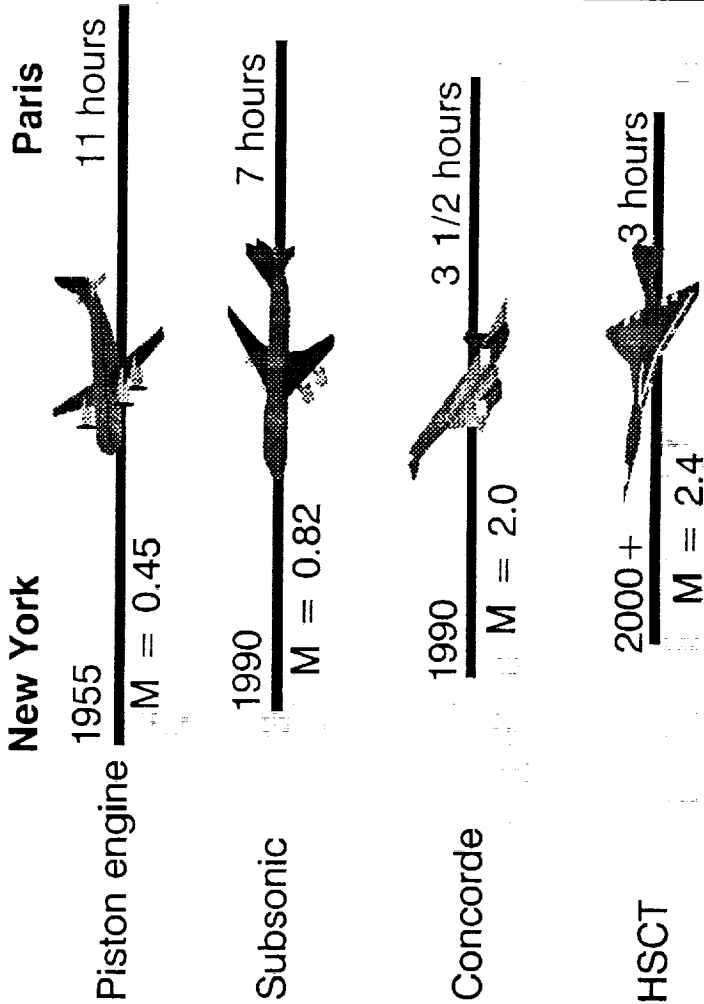
Economic Measures of Success for the HSCT

- The cost-price-market loop must close
 - Sufficient program (total units) to allow airframe and engine manufacturers to build and sell with a reasonable return on investment
 - Overall economics (operating plus ownership costs) that permit a reasonable return to the airline
 - Passengers appear to be willing to pay relatively modest surcharges over competing subsonic fares for roughly a 50% time savings
- Surcharge target is in the +10 to +20% range
- Current indications are that technologies could be available to achieve the target surcharge level

Making the World Smaller

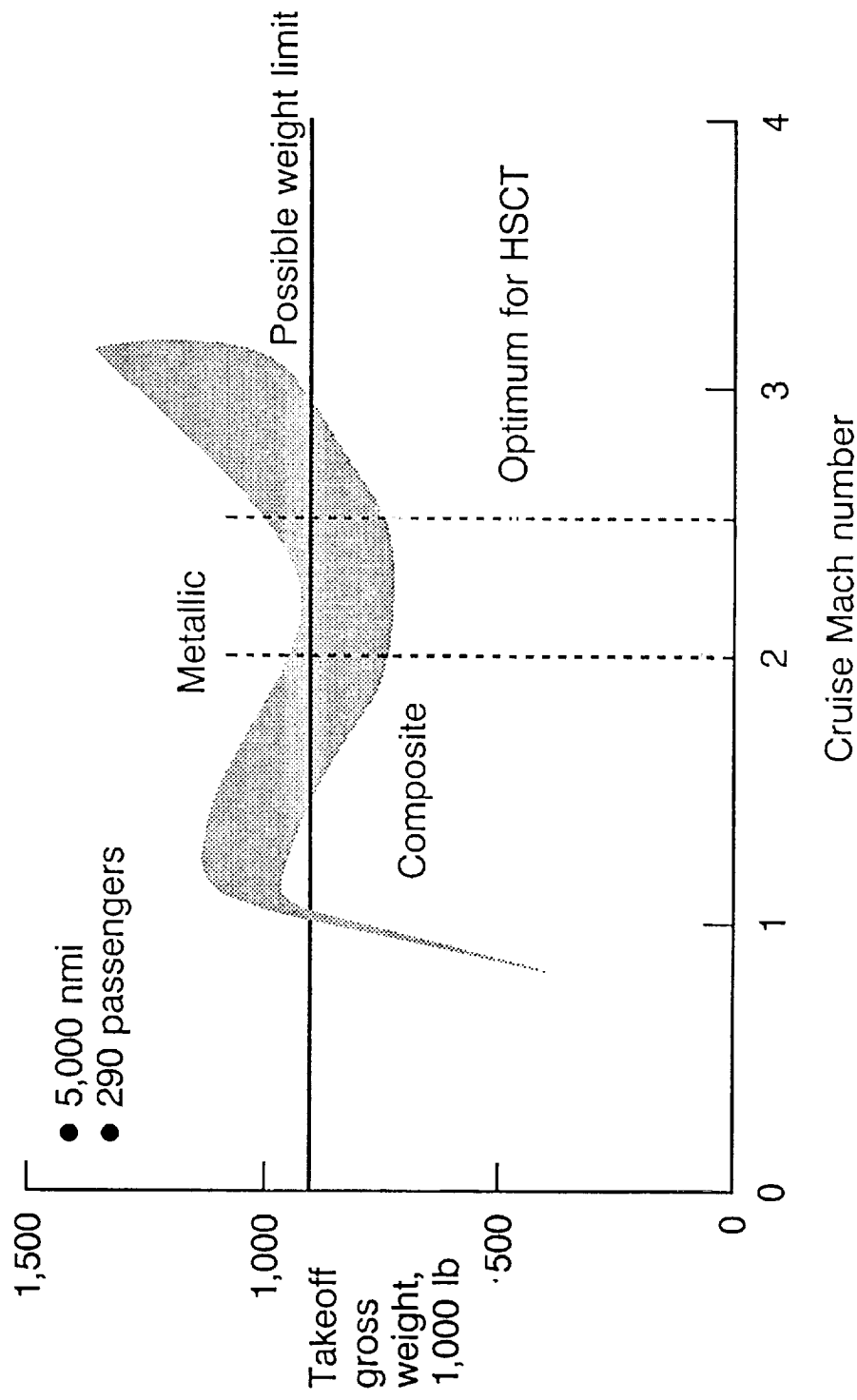
With High Speed Civil Transport

Economically and with positive environmental impact

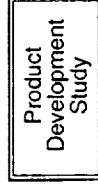


Typical fares (1990 dollars)			
Full economy \$1,800	Discount --	Average --	
\$ 857	\$ 250	\$ 500	
\$2,700	\$2,700	\$2,700	
\$ 950	\$ 290	\$ 550	

Effect of Cruise Mach Number on Maximum Takeoff Weight

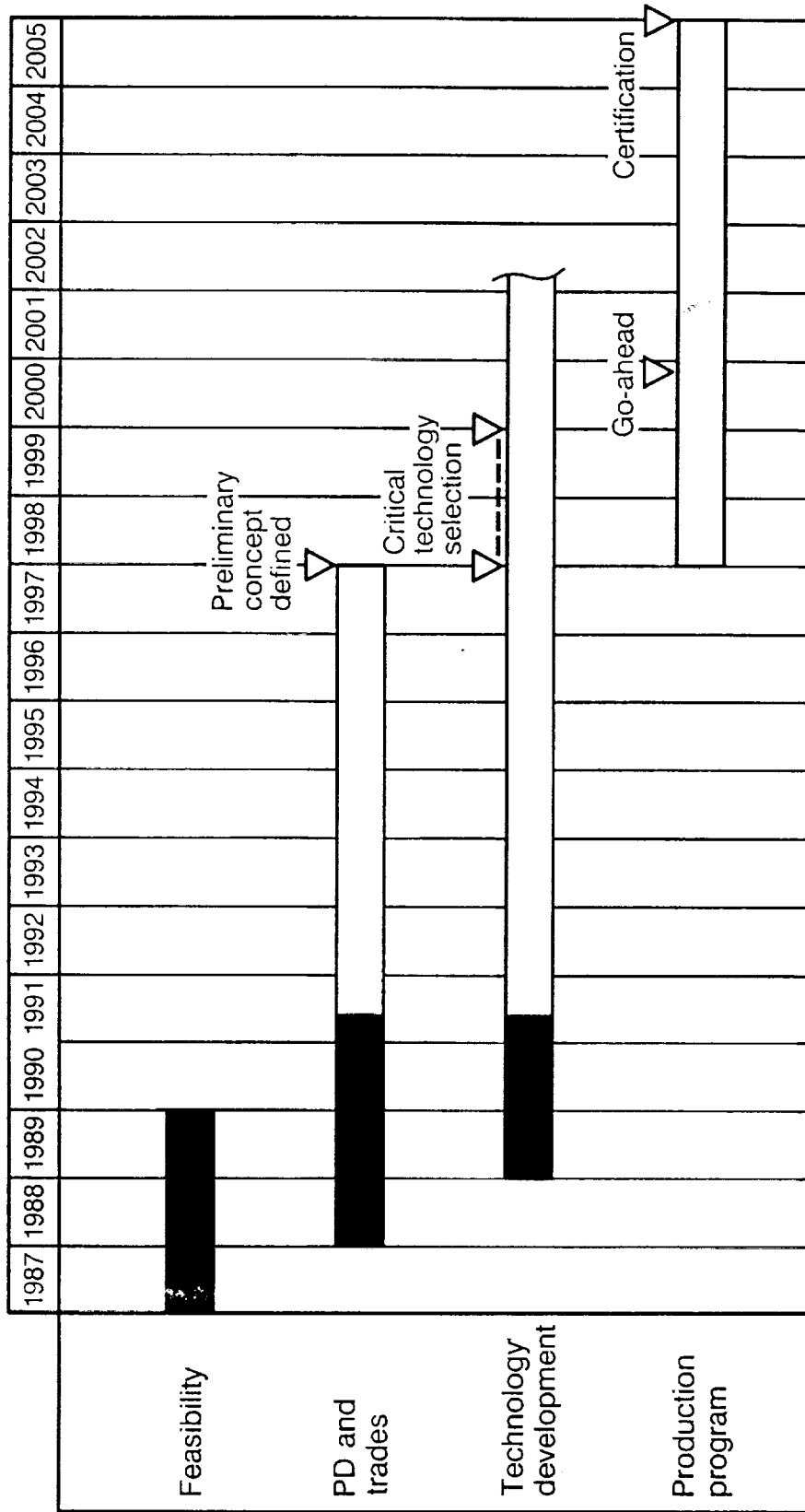


High Speed Civil Transport

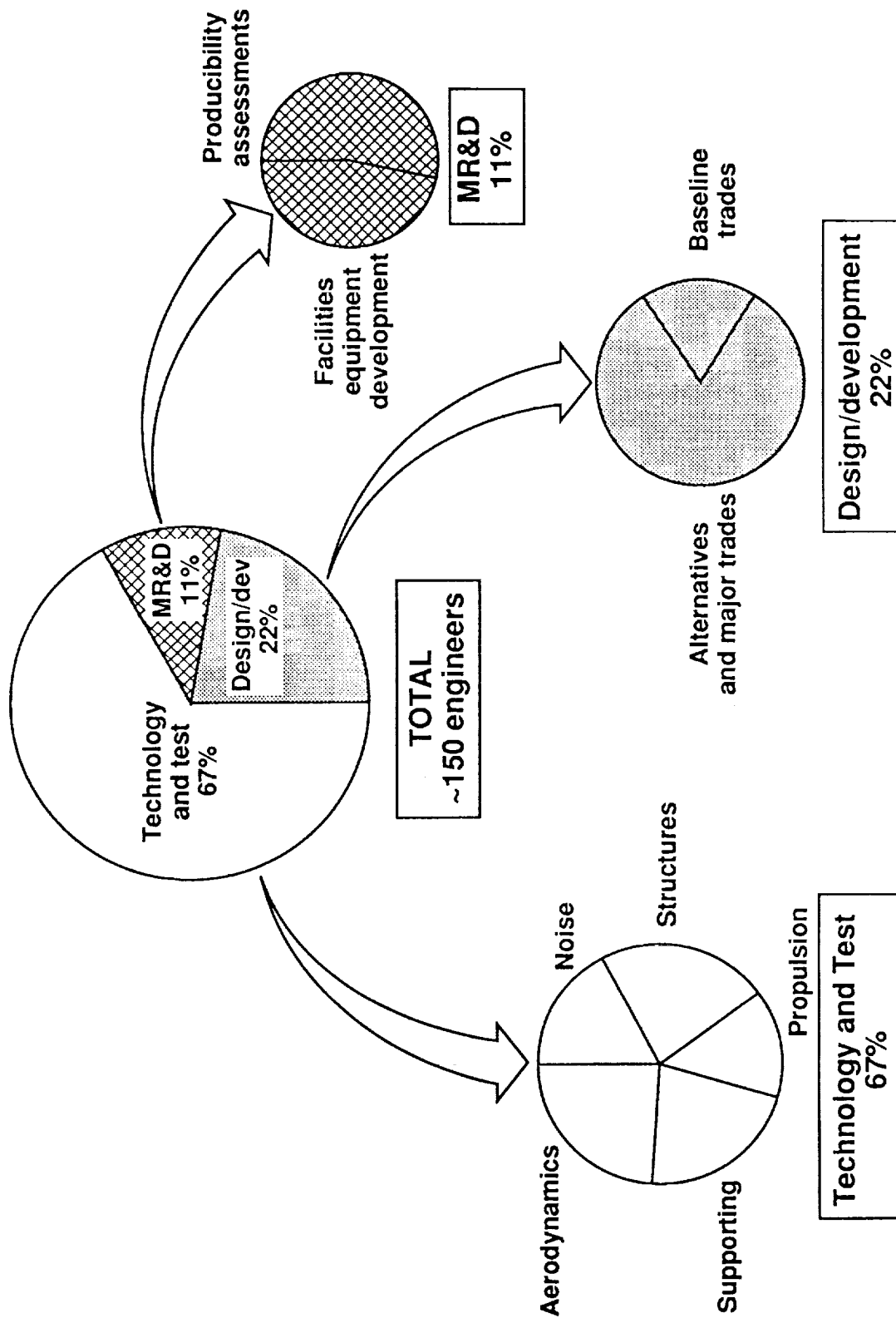


- Boeing has a significant study effort directed at development of a viable High Speed (Supersonic) Civil Transport for introduction into service early in the next century
- The program integrates technology development, aircraft design, manufacturing research, and airline requirements
- While the results of studies to date are encouraging, it is also clear that early, focused technology development is vital to the timing and ultimate success of the HSCT

HSCT Planning Schedule

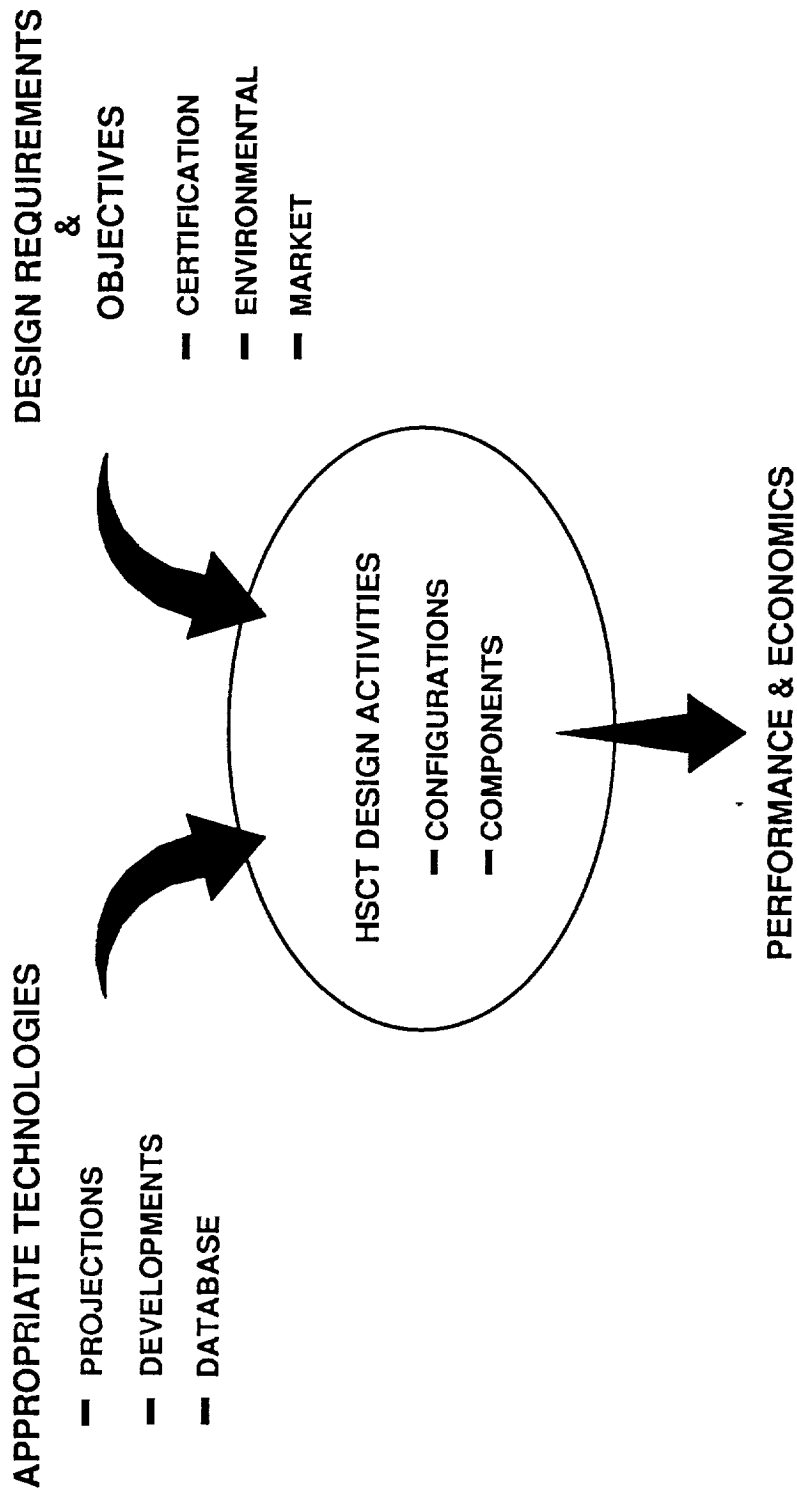


1991 HST Budget Breakdown



HSCT TECHNOLOGY PROJECTIONS AND PROGRESS

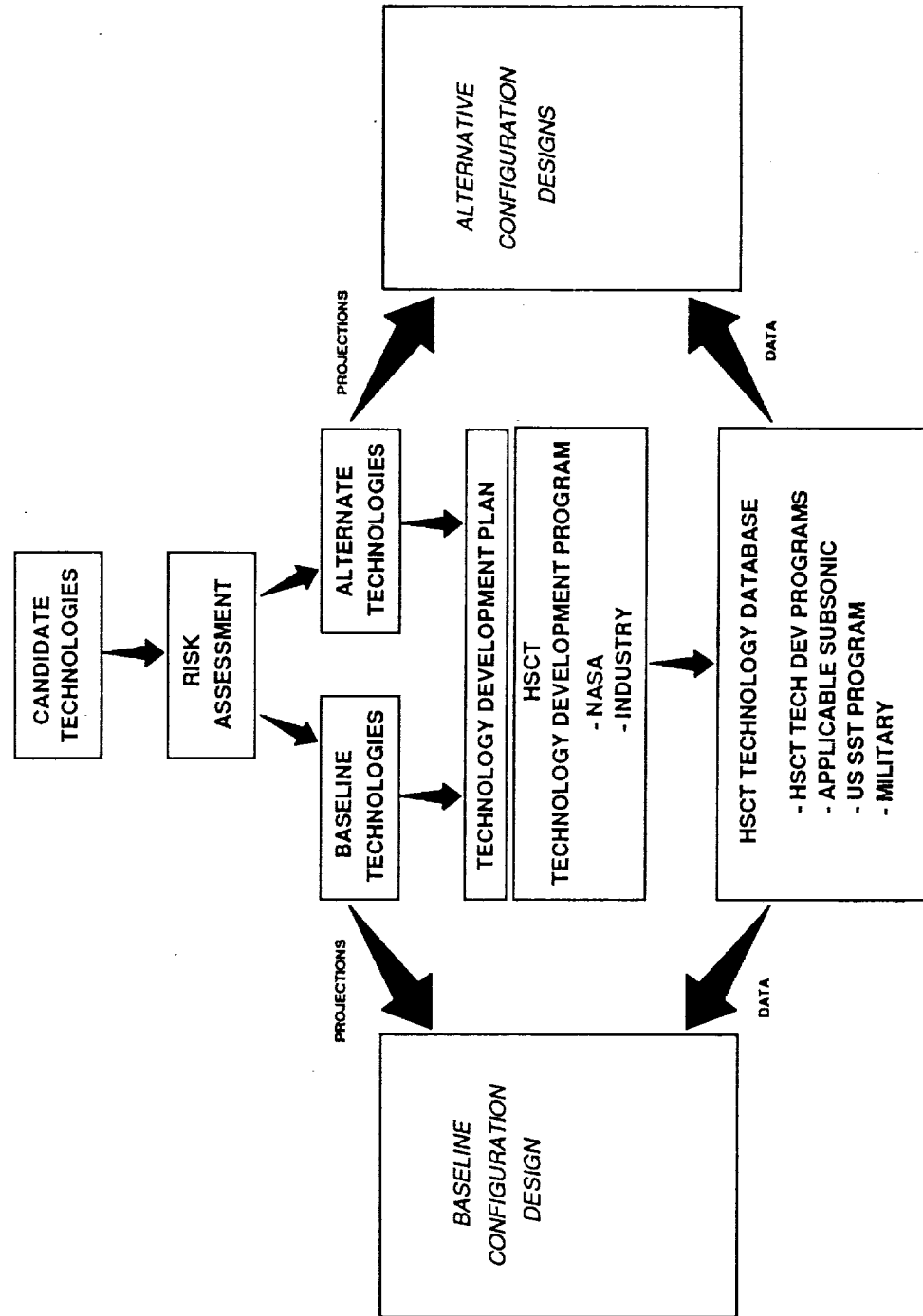
PERFORMANCE AND ECONOMICS DRIVERS



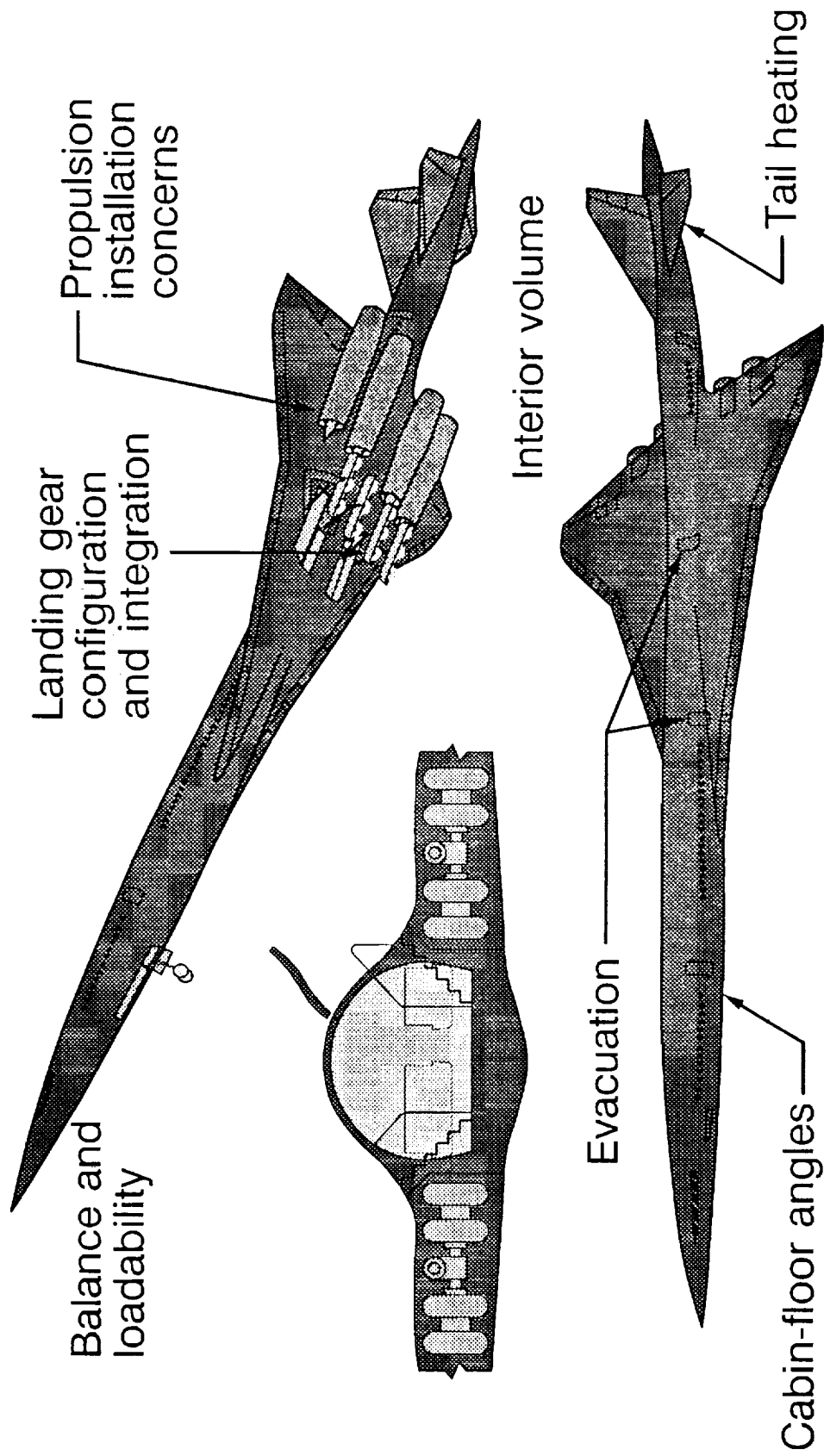
MSG: HSCT PERFORMANCE & ECONOMICS ARE DEPENDENT ON ACHIEVING HIGH CONFIDENCE LEVEL IN KEY PROJECTED TECHNOLOGIES BY GO AHEAD.

HSCT TECHNOLOGY PROJECTIONS AND PROGRESS

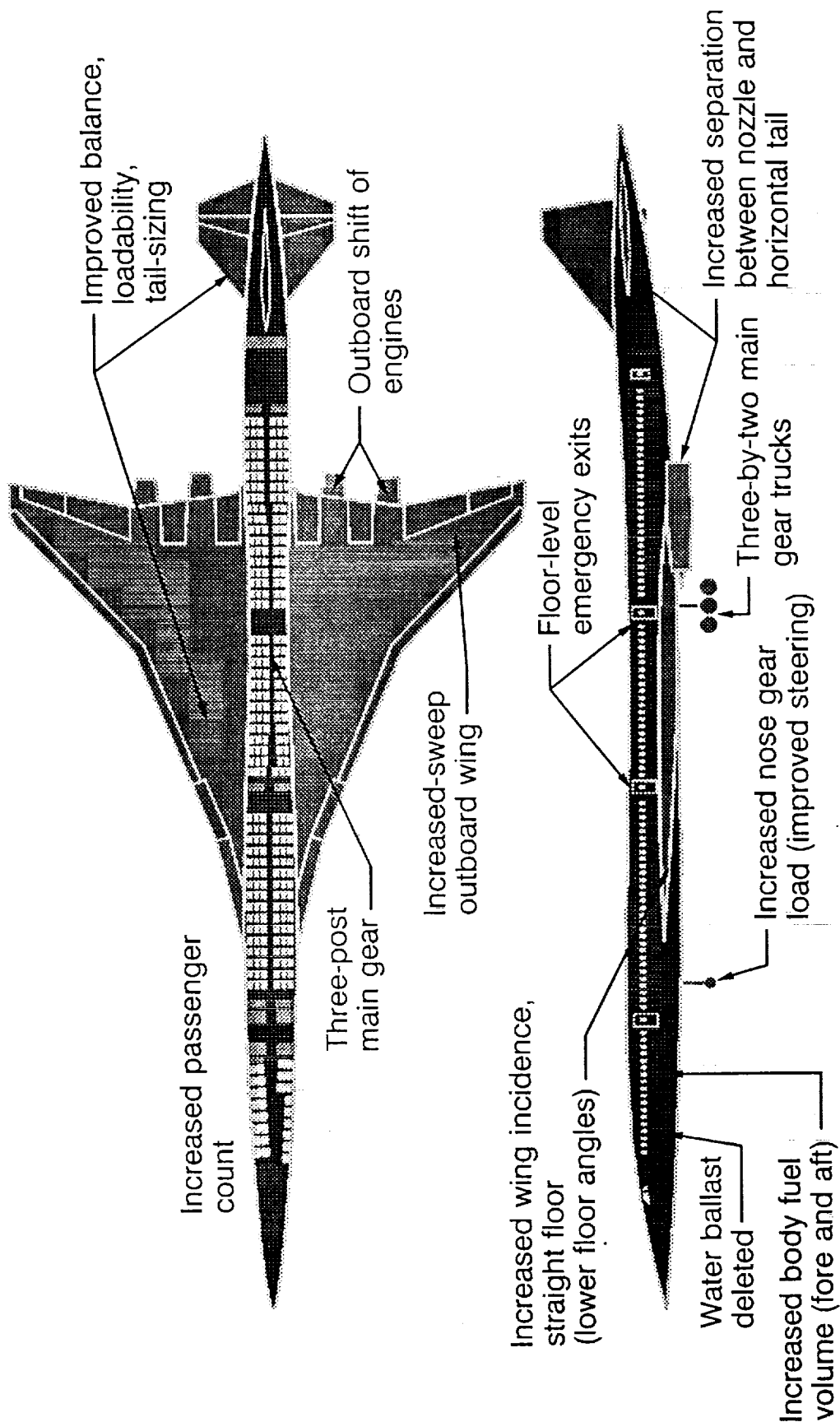
TECHNOLOGY PROJECTION AND DEVELOPMENT PROCESS



HSCT Blended Configuration Design Concerns

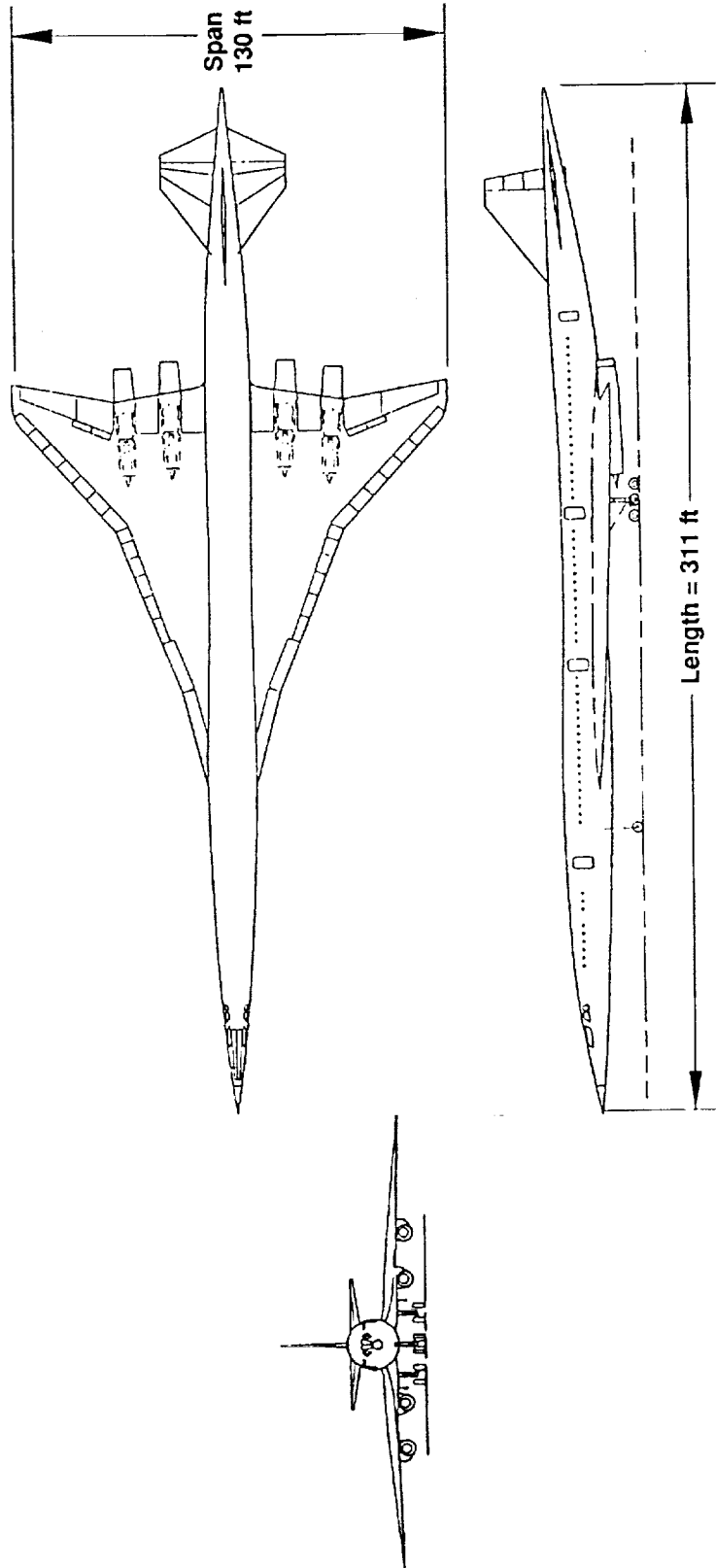


Unblended Configuration



High Speed Civil Transport

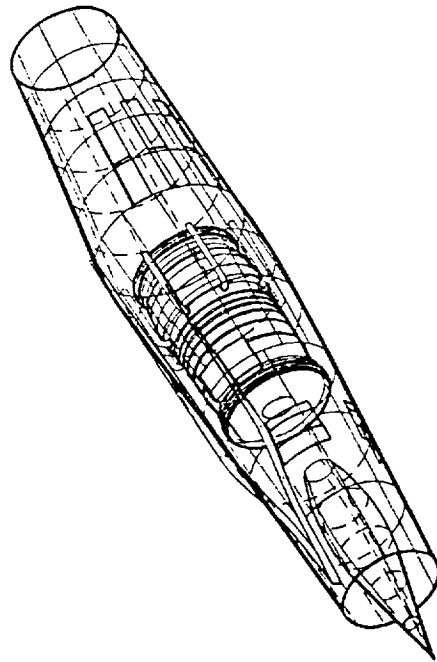
Baseline Configuration



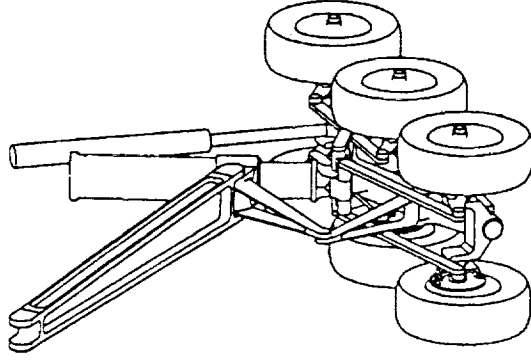
Range	5,000 nmi
Payload	302 passengers tri-class
MGW	705,000 lbs
OEW	275,000 lbs
Noise	FAR 36 stage III
Wing area	7,100 ft ²

High Speed Civil Transport

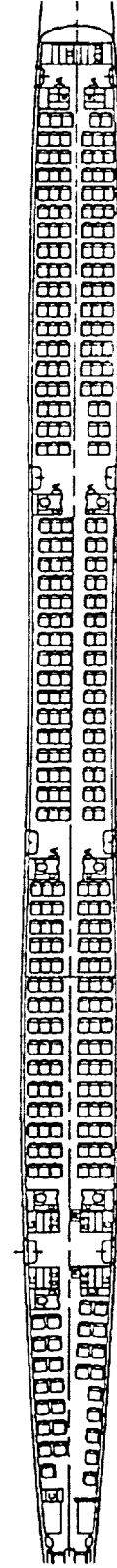
Baseline Features



Suppressed turbojet propulsion system



3-post 6-wheel steerable MLG



28 first class
38 in pitch

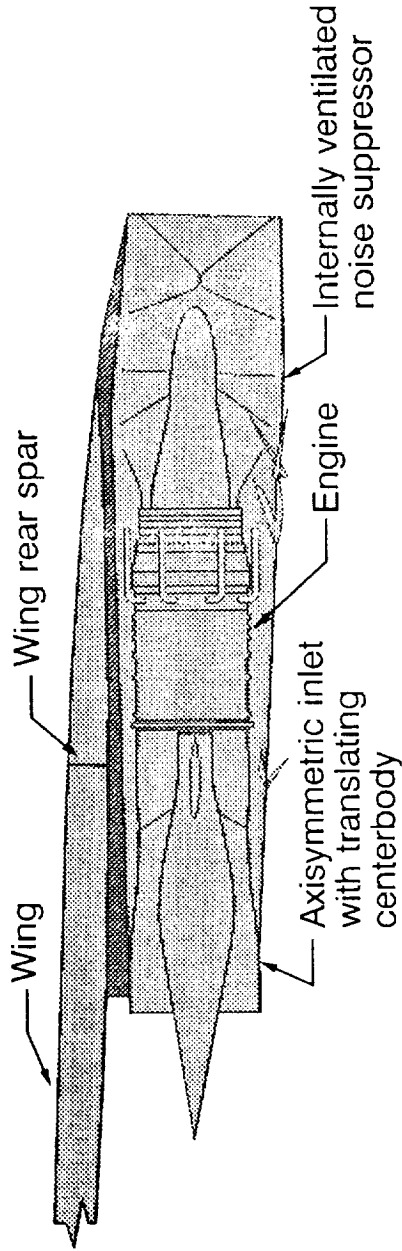
60 business class
36 in pitch

302 passengers

214 tourist class
33/34 in pitch

Interior arrangement

Baseline Engine Features



Engine	Turbine bypass turbojet
Nozzle	Internally ventilated noise suppressor
Inlet	Axisymmetric mixed-compression with translating centerbody
Combustor	Low emissions (5 to 8 lb NO _x /1,000 lb fuel)
Engine maximum airflow	460 lb/s
Takeoff thrust	62,200 lbs at M = 0.2
Pod length	345 in
Pod inlet diameter	53.9 in
Pod maximum diameter	73.8 in
Pod weight	14,100 lb



HIGH SPEED CIVIL TRANSPORT

BRITISH AIRWAYS REVIEW

PURPOSE

"BEGIN A PROCESS THAT WILL LEAD TO AIRLINE PARTICIPATION IN
THE ASSESSMENT AND DESIGN OF AN ECONOMICALLY VIABLE HSCT. "

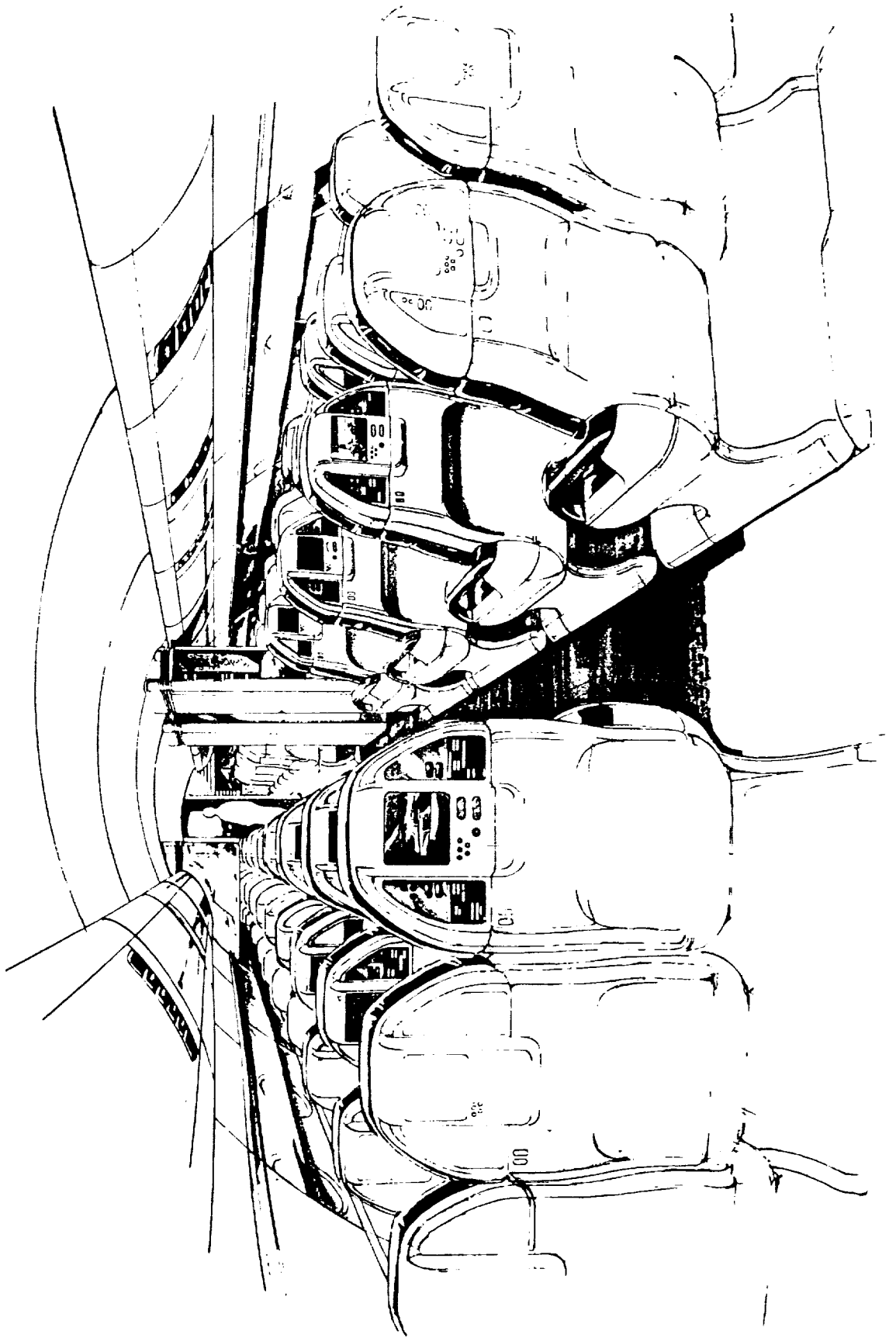
TODAY'S MEETING

- SHARE WITH BRITISH AIRWAYS OUR ASSUMPTIONS AND STUDY RESULTS.
- LISTEN TO YOUR FEEDBACK.
- BEGIN TO PLAN FUTURE HSCT ACTIVITY WITH BRITISH AIRWAYS.



INTERIORS

- **DESIGN REQUIREMENTS & OBJECTIVES**
- **INTERIOR ARRANGEMENT**
- **CROSS-SECTIONS**
- **CARGO STUDIES**
- **EVACUATION ISSUES**
- **TEAGUE'S INTERIOR CONCEPTS**

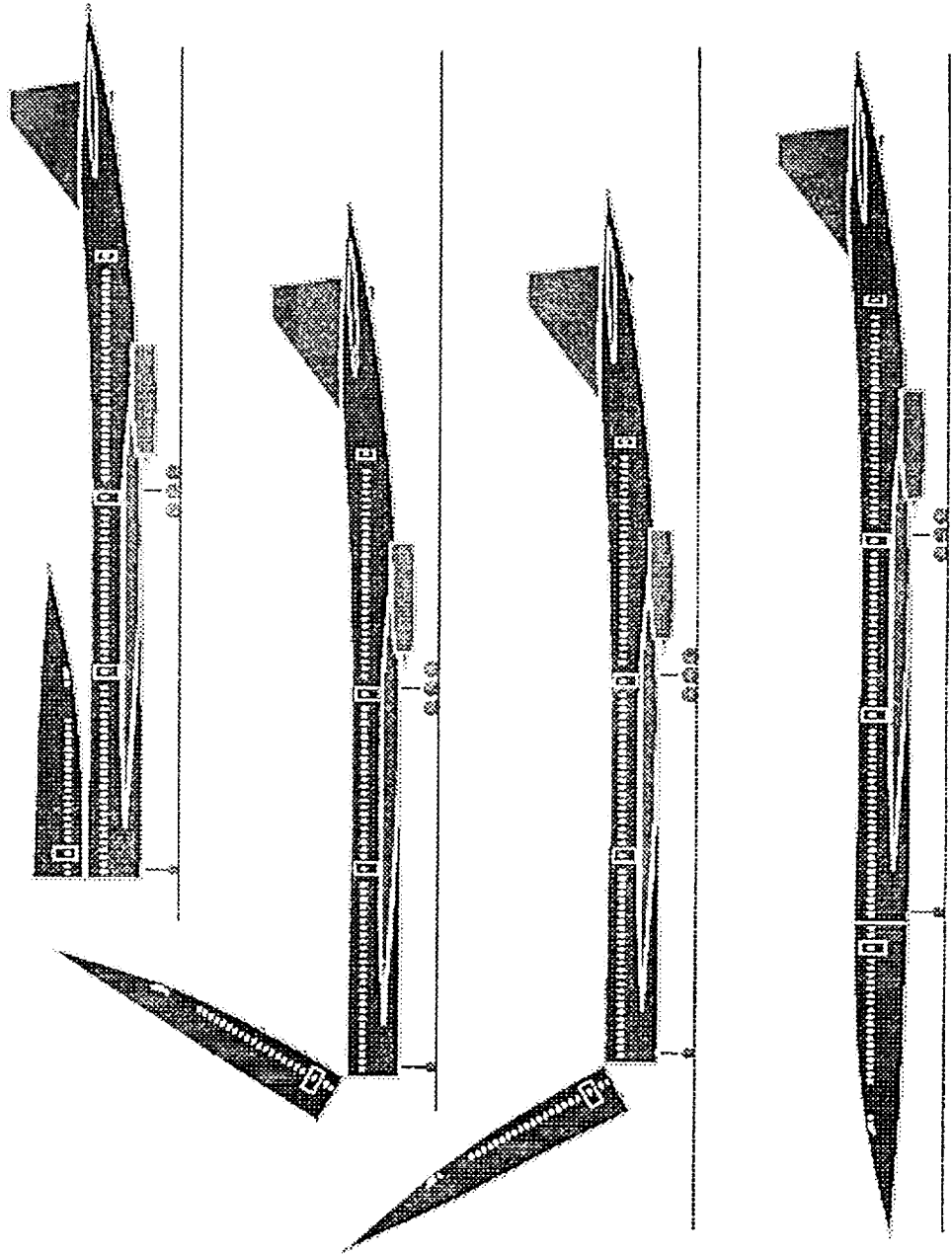




AIRPORT ISSUES

- **DESIGN REQUIREMENTS & OBJECTIVES**
- **AIRPORT PARKING**
- **RUNWAY LOADING**
- **TAXIWAY TURNING**
- **TURN-AROUND**
- **GROUND HANDLING**
- **FLIGHT DECK OVERHANG**

Preferred Airline Configuration



“Nonproblems”

- Field length requirements - same as large subsonic aircraft
- Runway separation - no more critical than large subsonic aircraft
- Turbulence impact on operations - less critical than large subsonic aircraft
- Fuels - jet A is satisfactory

HIGH SPEED CIVIL TRANSPORT

KEY PROGRAM ISSUES

TECHNICAL

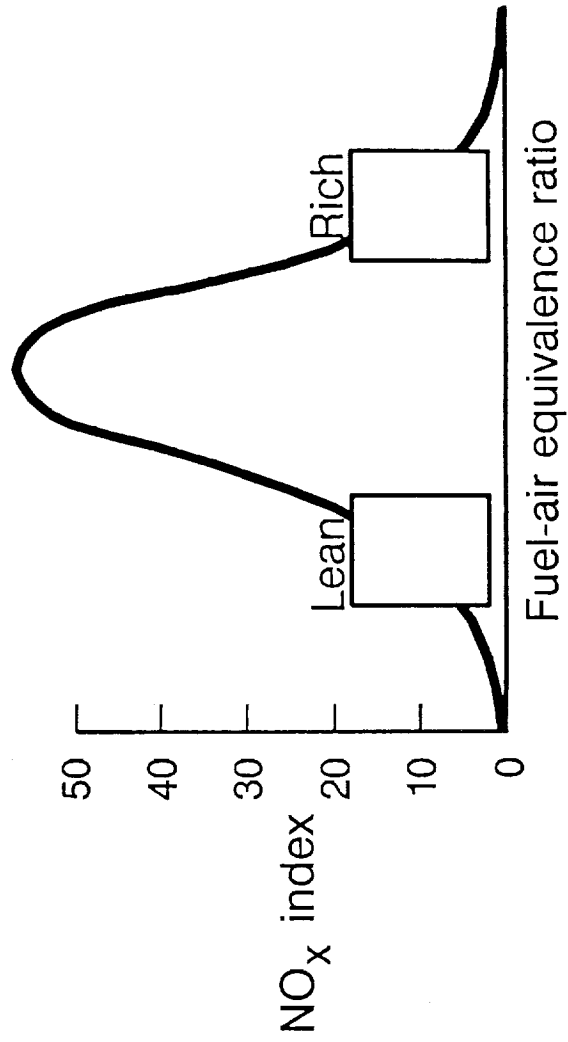
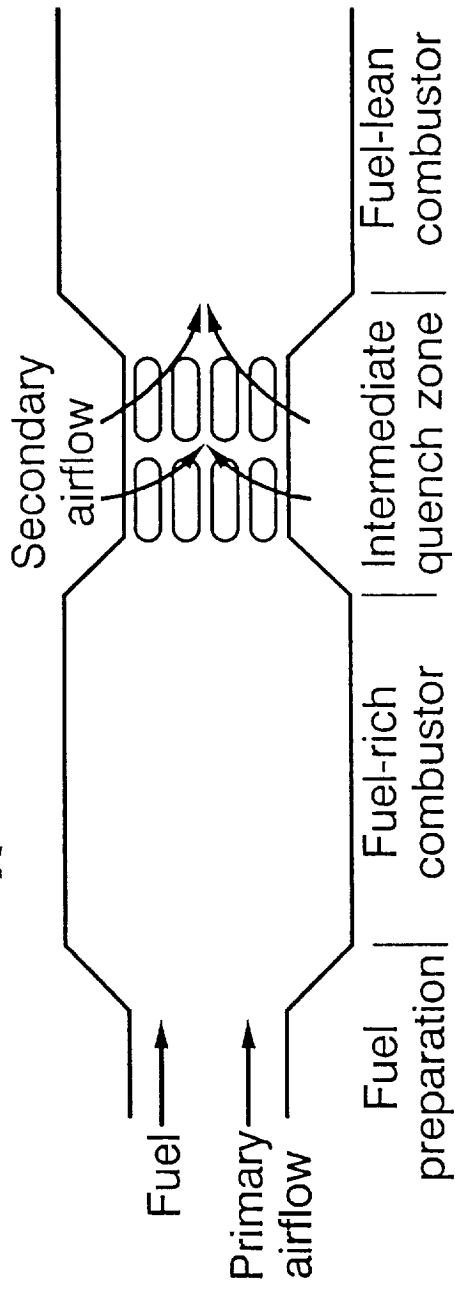
AIRFRAME

- HIGH TEMPERATURE COMPOSITE STRUCTURE
- JET NOISE SUPPRESSORS
- ENGINE INLET
- AERODYNAMICS AND CONTROLS

ENGINE

- LOW EMISSIONS BURNERS
- VARIABLE CYCLE ENGINE CORE

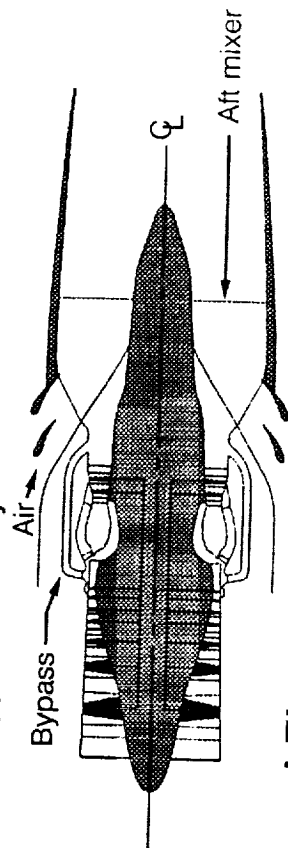
Low NO_x Combustor Concept



Engine Developments

Pratt & Whitney

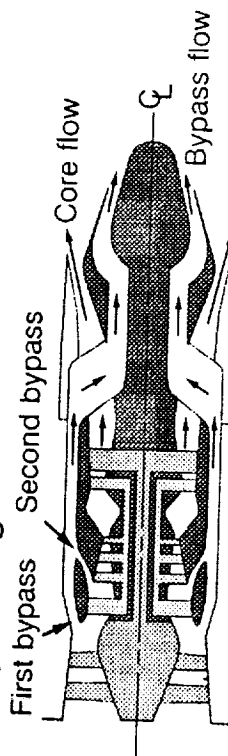
Turbine bypass turbojet



- Single spool
- Simple concept
- High-temperature materials
- Noise-suppression nozzle
- Low-emission combustor

General Electric

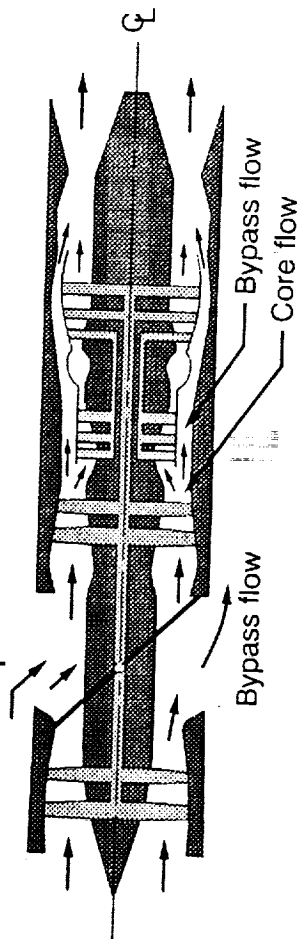
Variable cycle engine



- Dual spool
- Variable geometry
- High-temperature materials
- Low-emission combustors
- Noise-suppression nozzle

Rolls Royce/Snecma

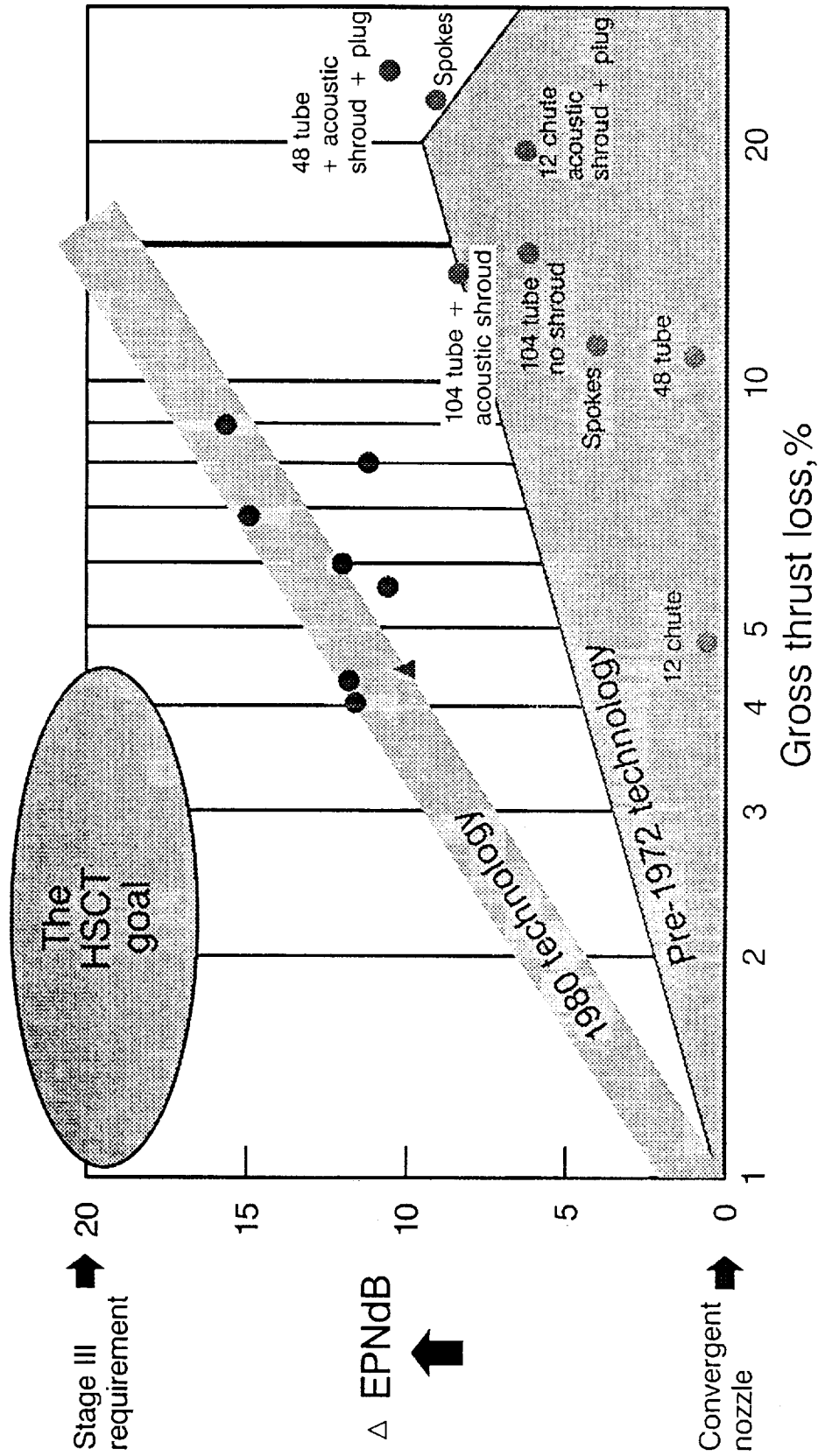
Tandem fan concept



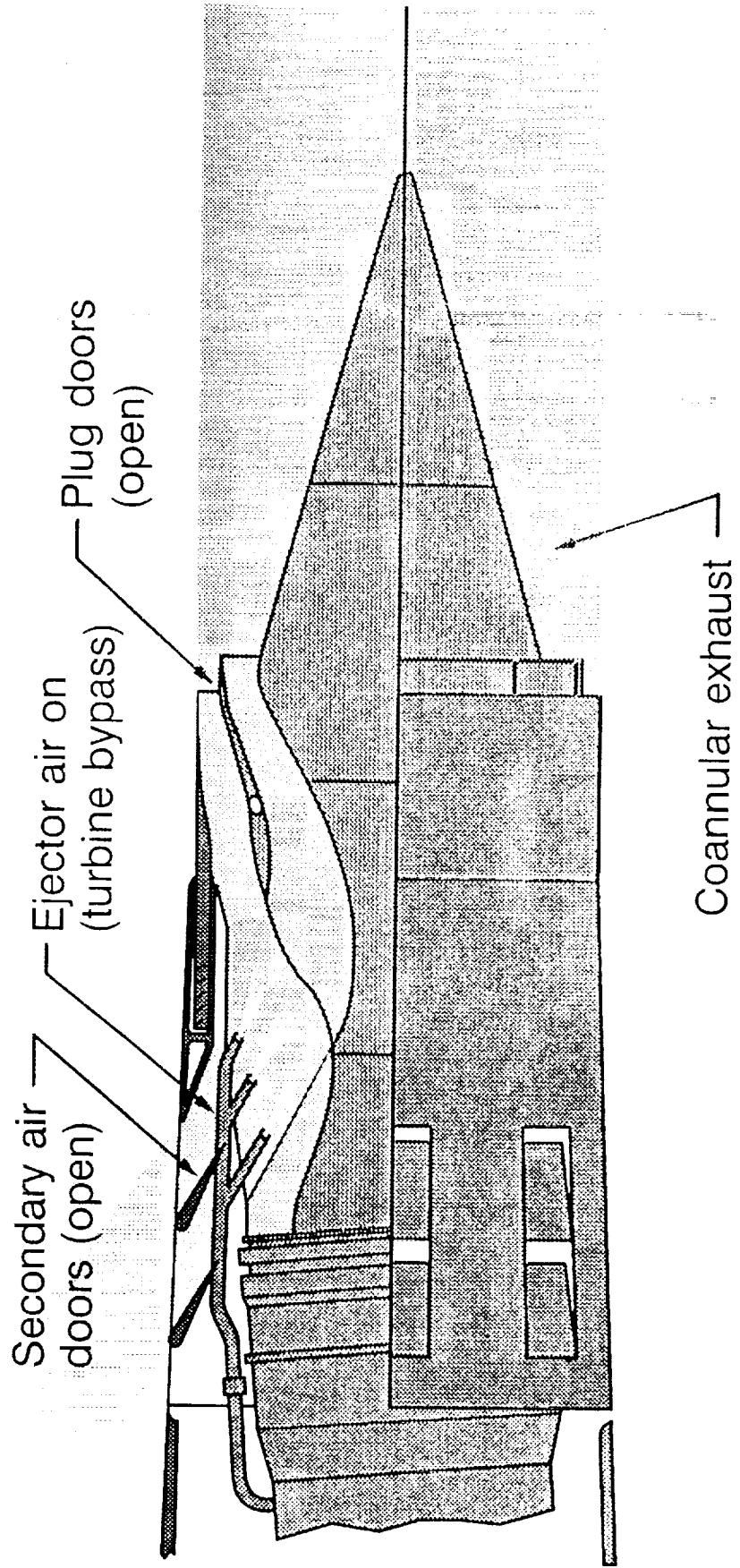
- Dual spool
- Big valve
- Heavier
- Longer
- Conceptual design

Jet Suppressor Technology

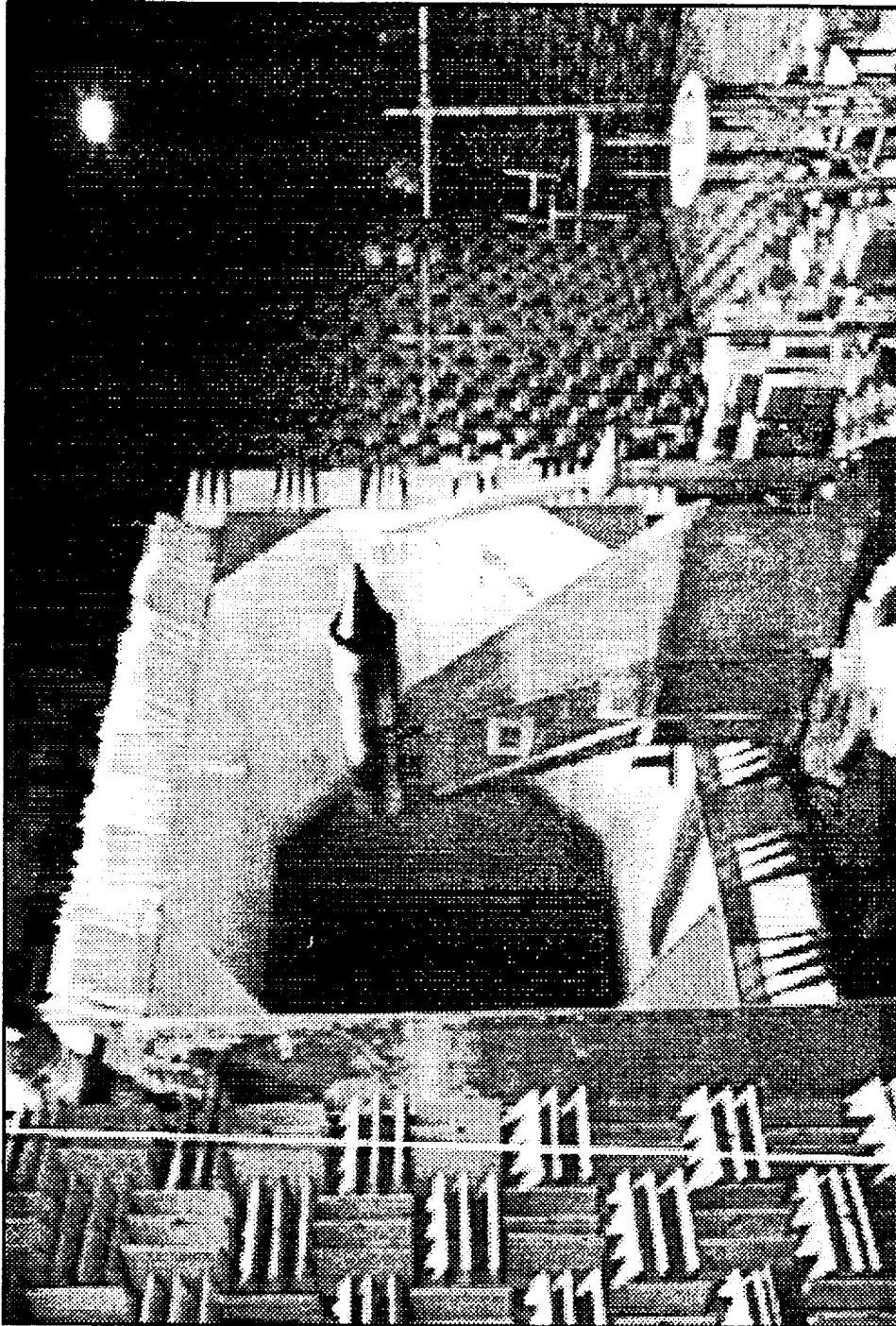
Late 1980s



1989 NACA Nozzle Concept

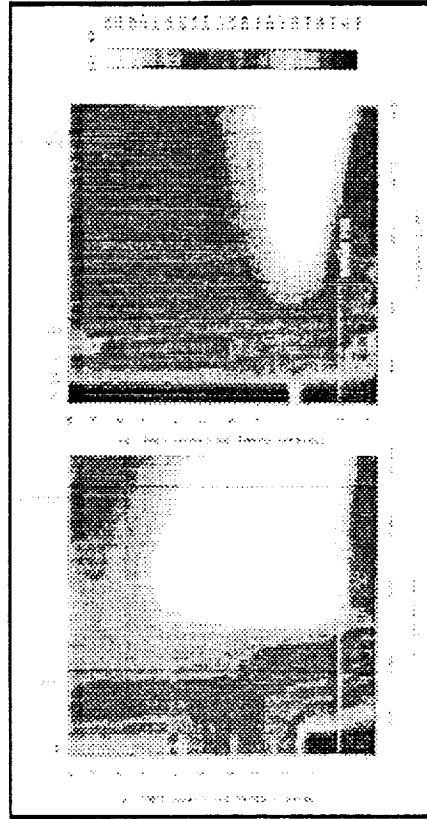


Large-Scale Aeroacoustic Facility (LSAF)

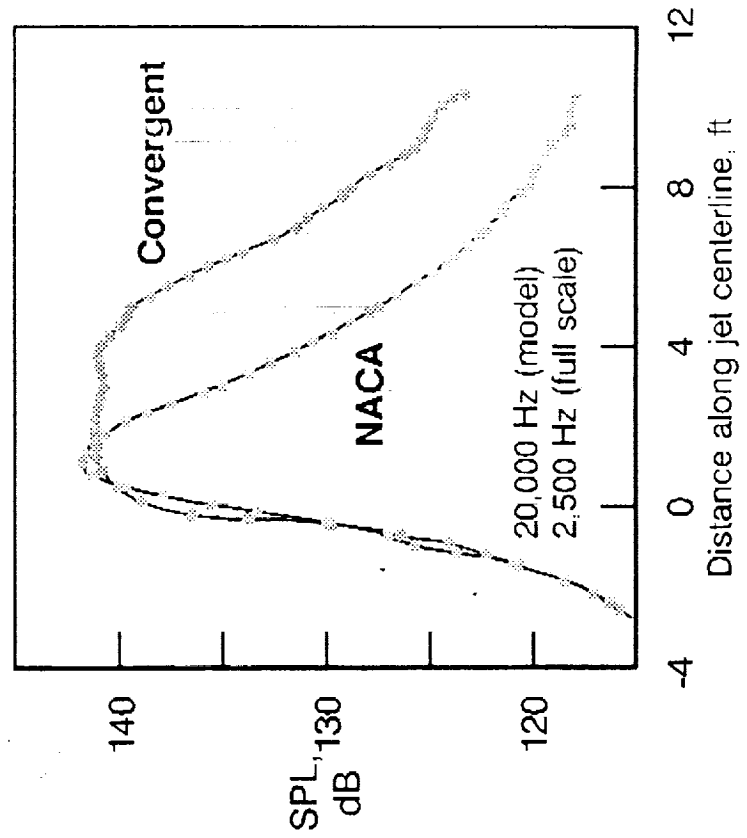


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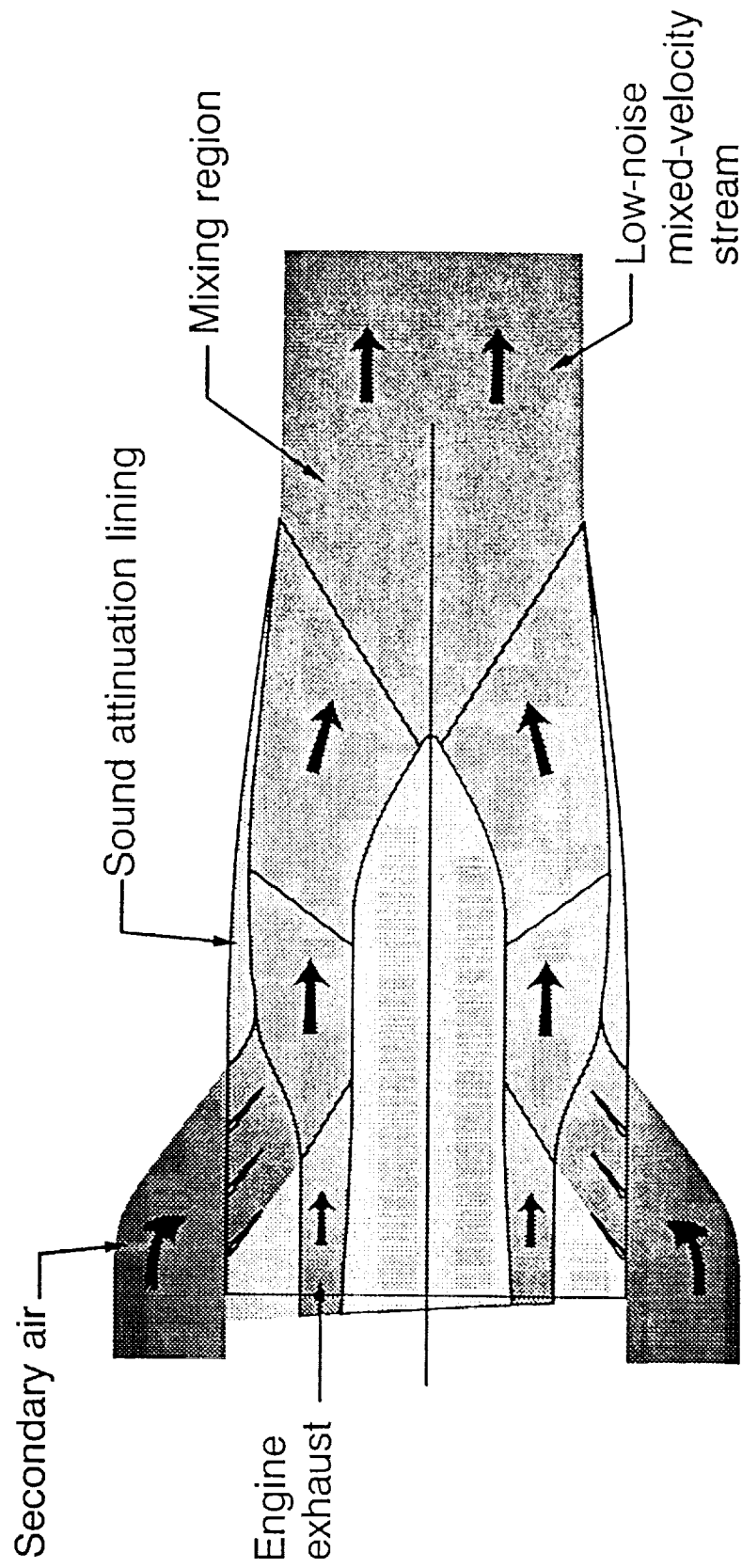
NACA Nozzle Results



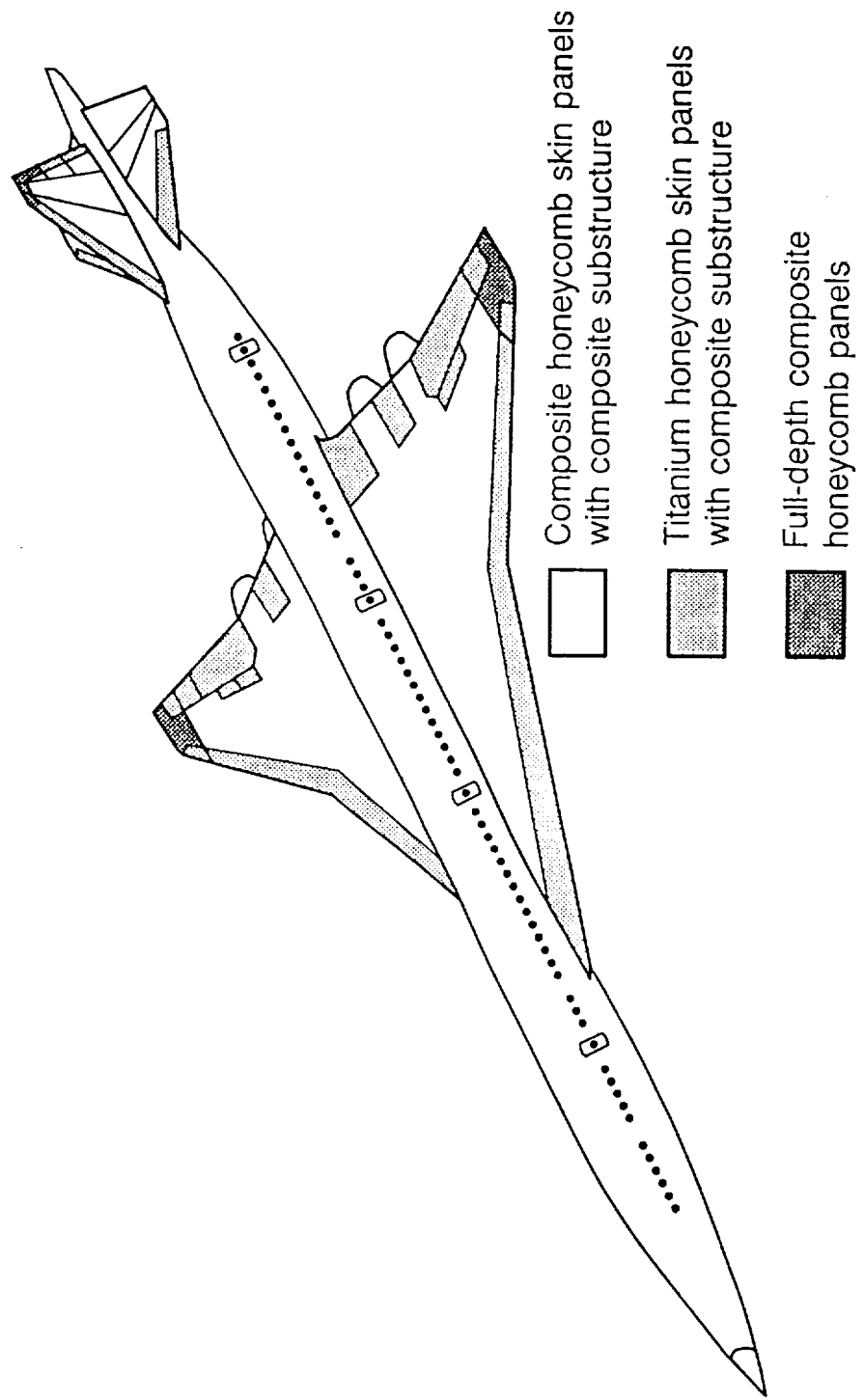
- Low-frequency jet noise reduced
- Low thrust loss
- Mixing noise remained high
- Concept fell short of expectations



Internally Mixed Ejector - Suppressor Nozzle Concept






Proposed Usage of Materials for the HSCT



Materials Technology Development Tasks

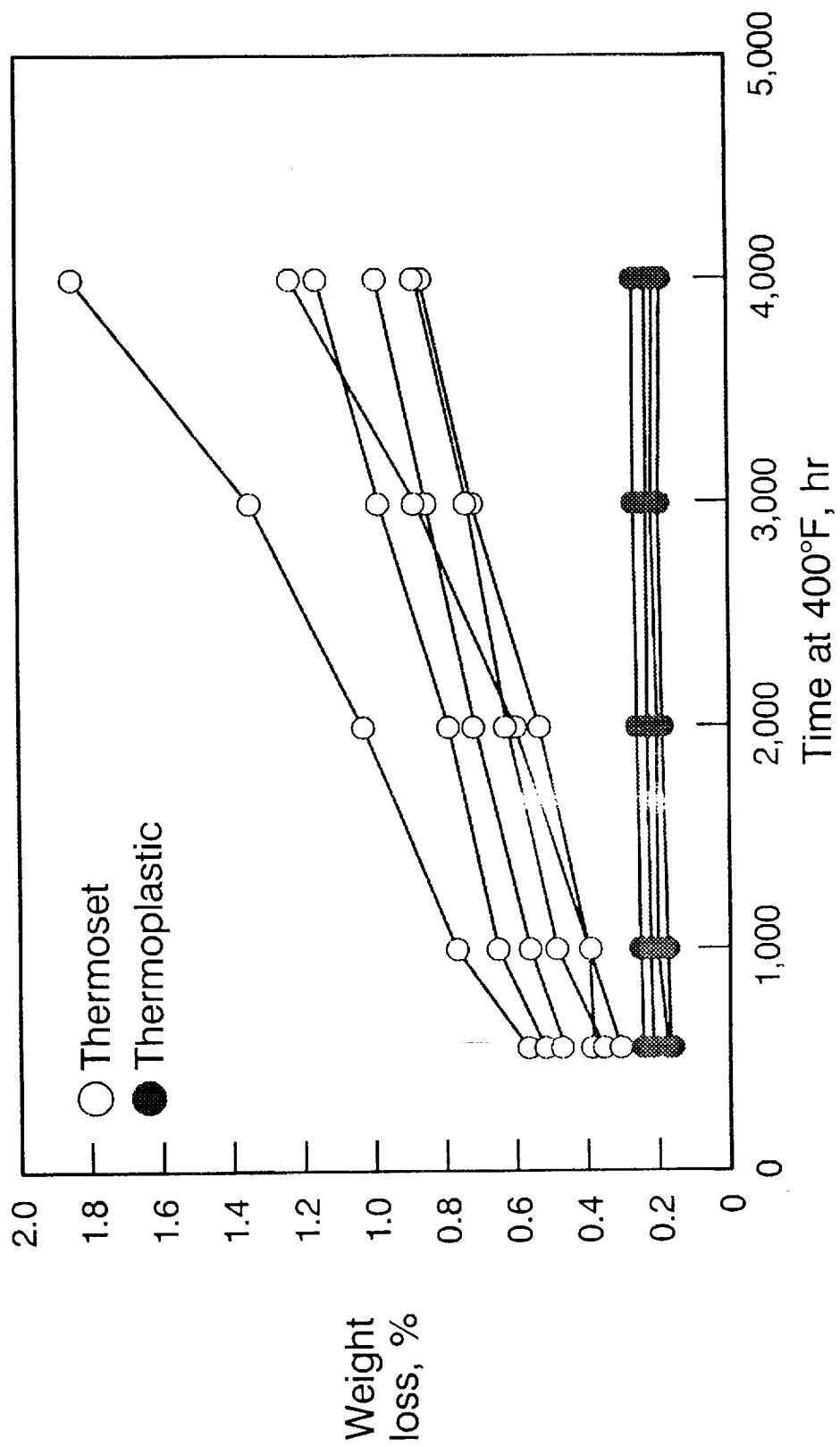
- Structural materials
 - Composites
 - Metals
- Adhesives
- High-temperature sealants
- Finishes
- Lubricants

Structural Composites Screening Matrix

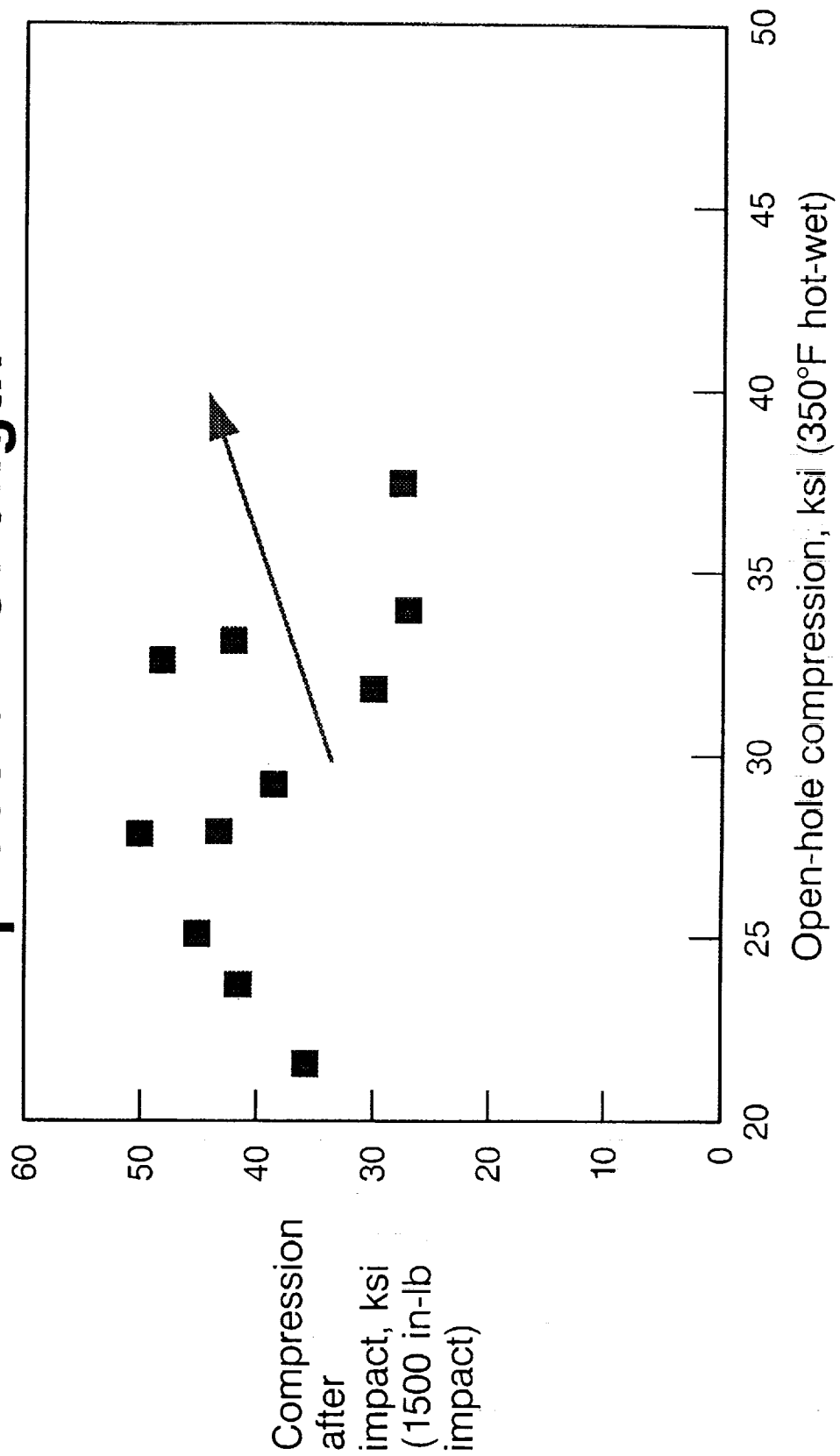
-  Scheduled
-  In testing
-  Complete

	Thermoplastics						Thermosets										
	1	2	3	4	5	6	1	2	3	4	5	6	7	8	9	10	11
Open-hole compression	●	●	●	●	●	◐	●	●	●	●	●	●	●	●	●	●	○
Open-hole tension	●	●	●	●	●	◐	●	●	●	●	—	●	●	●	●	●	○
Uni compression	●	●	●	—	—	◐	●	●	●	●	—	—	—	—	●	●	◐
Uni tension	●	●	●	—	—	◐	●	●	●	●	—	—	—	—	●	●	◐
CAI	●	●	●	●	●	◐	●	●	●	●	●	●	●	●	●	●	○
G _{IC}	●	—	●	—	—	◐	●	●	●	●	—	—	●	●	●	●	◐
G _{IIc}	●	—	●	—	—	◐	●	●	●	●	—	—	●	●	●	●	◐
Fluid sensitivity	●	●	●	●	●	●	●	●	●	●	—	●	●	●	●	●	○
Compressive interlaminar shear	◐	●	●	●	●	●	●	●	●	●	●	—	—	●	●	●	◐

Isothermal Aging

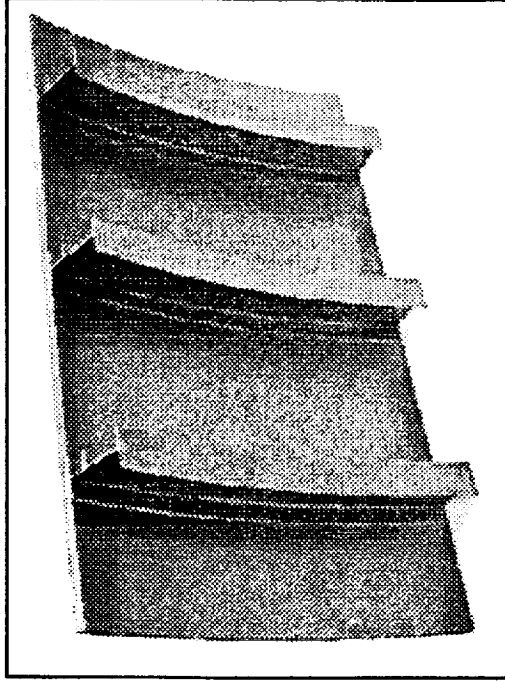


Damage Tolerance Versus Compression Strength

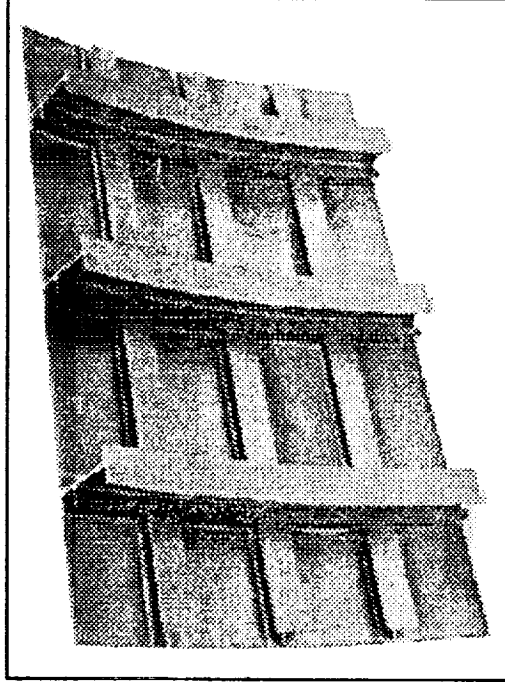


Manufacturing Research and Development

3- by 5-ft Body Panels



Honeycomb panel

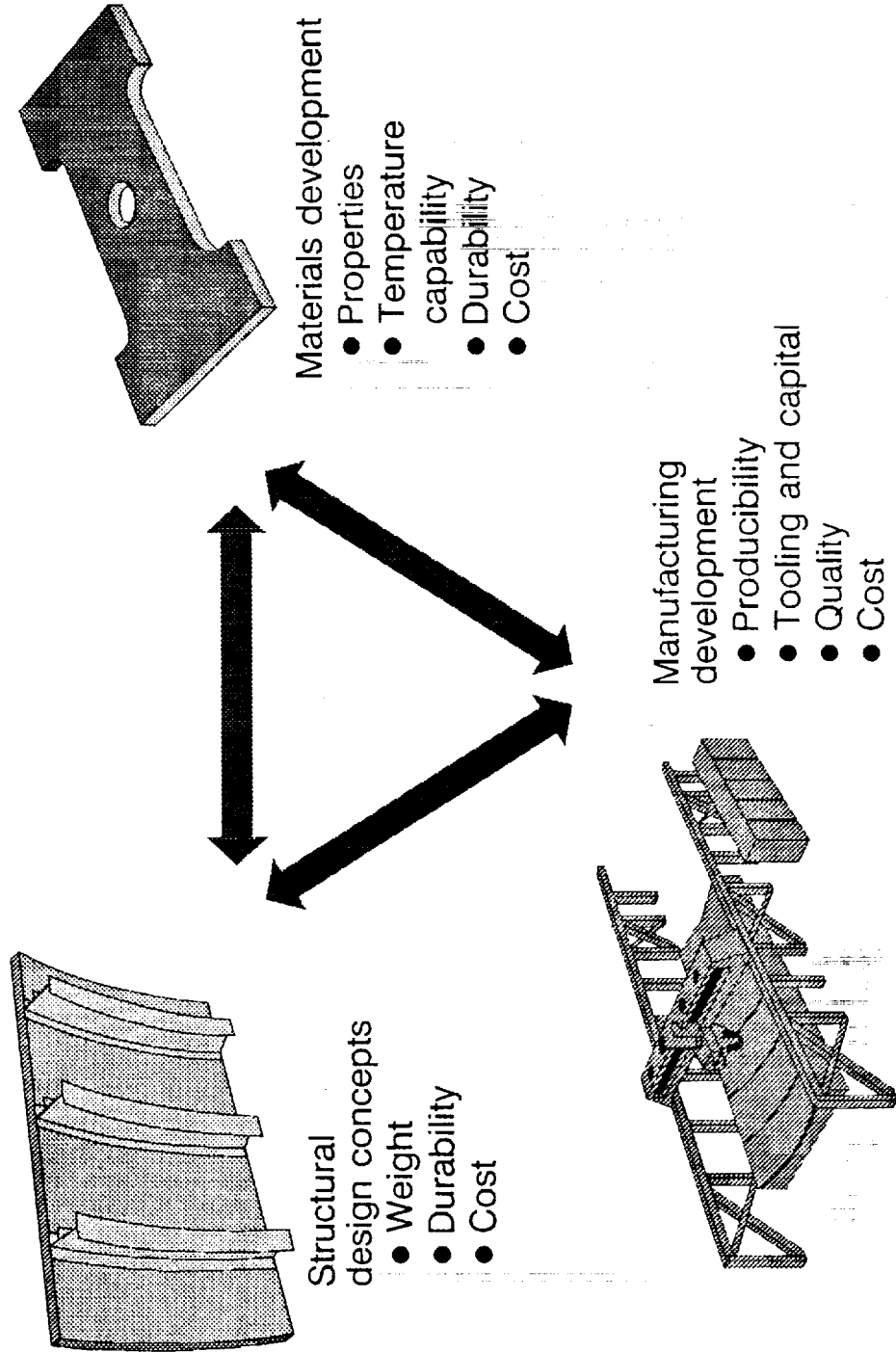


Skin stringer panel

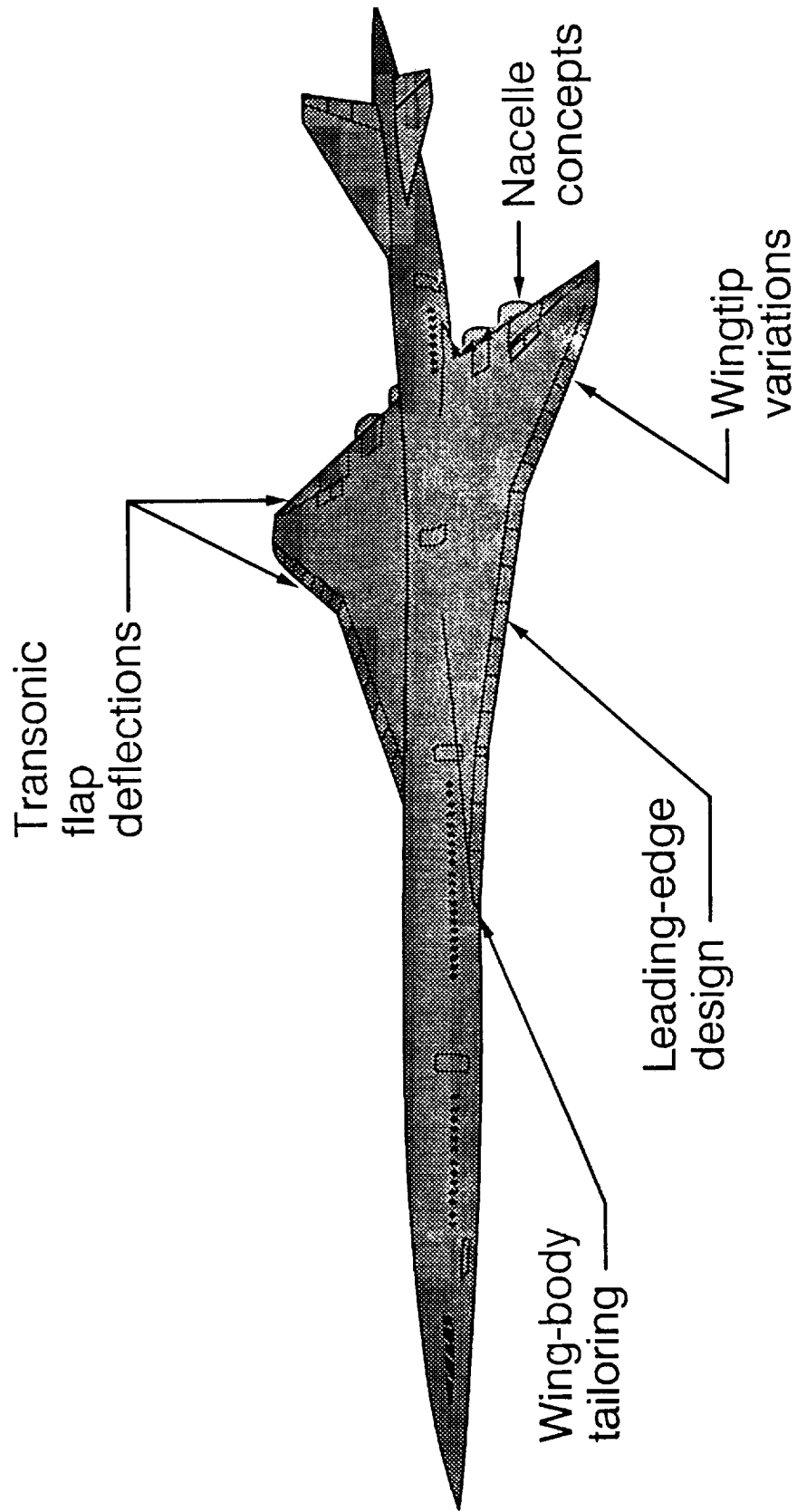
Producibility issues

- Cure cycle optimization
- Layup properties
- Titanium-core bonding
- Laminate thickness over core
- Bagging requirements

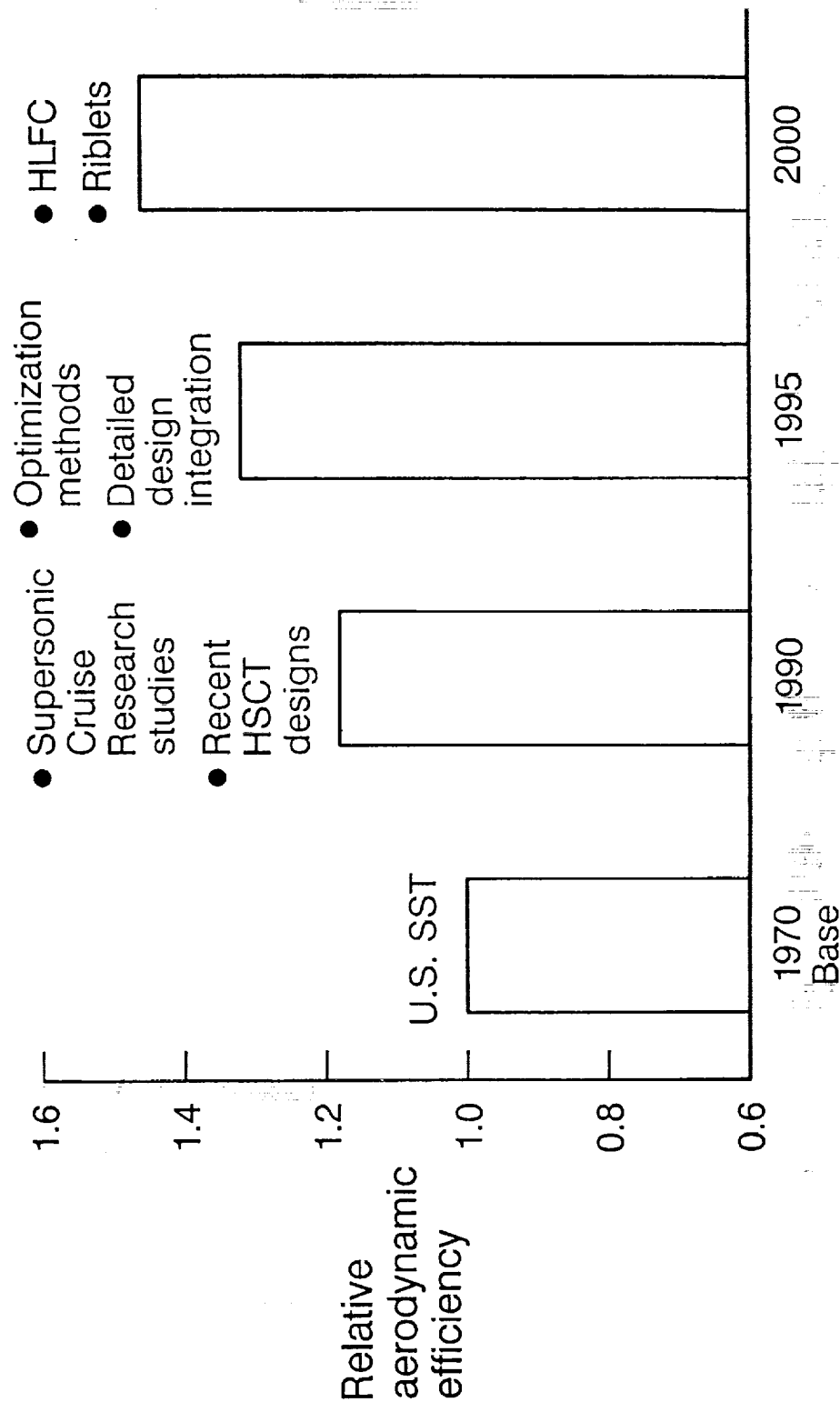
Composite Structure Development



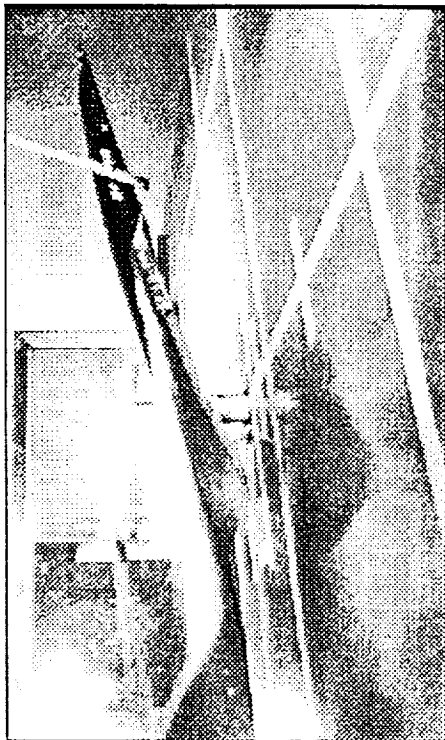
High-Speed Aero Optimization



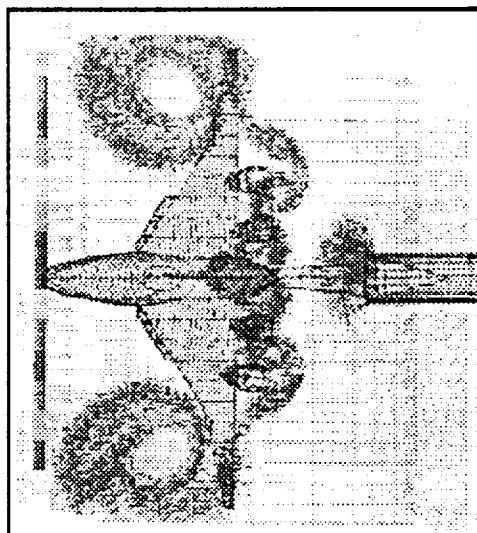
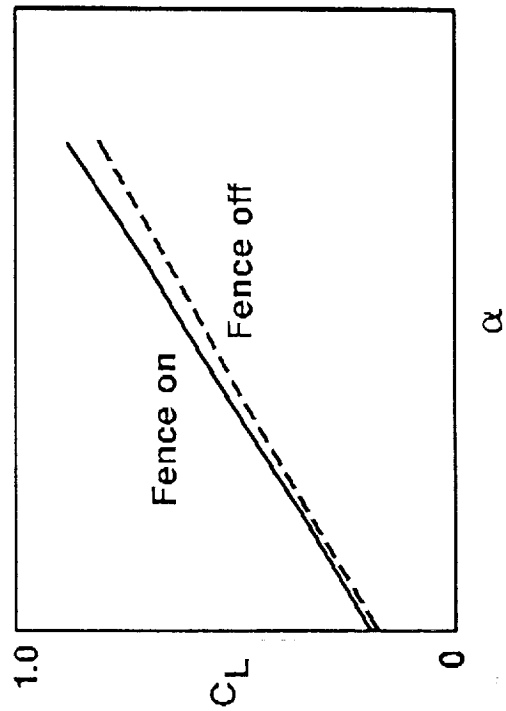
Aerodynamic Efficiency Improvement Projections



Vortex Fence

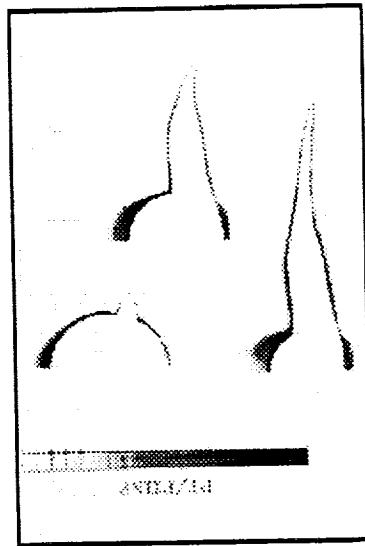


Effect of Vortex Fence in Ground Effect

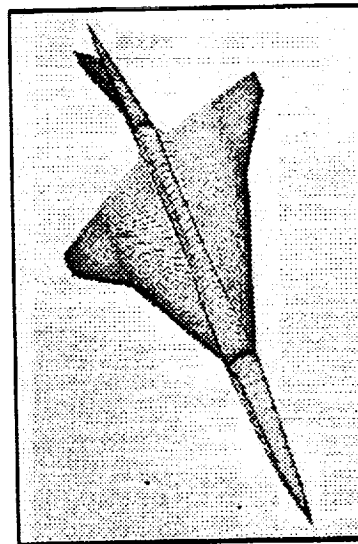


High-lift Vortex Amplification

High-Speed Aerodynamics



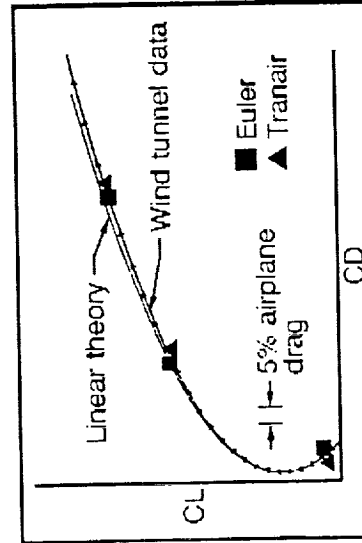
Flow quality
Parabolized Navier-Stokes
(Total pressure)



Drag prediction
Euler
Full potential (Tranair)
Linear potential

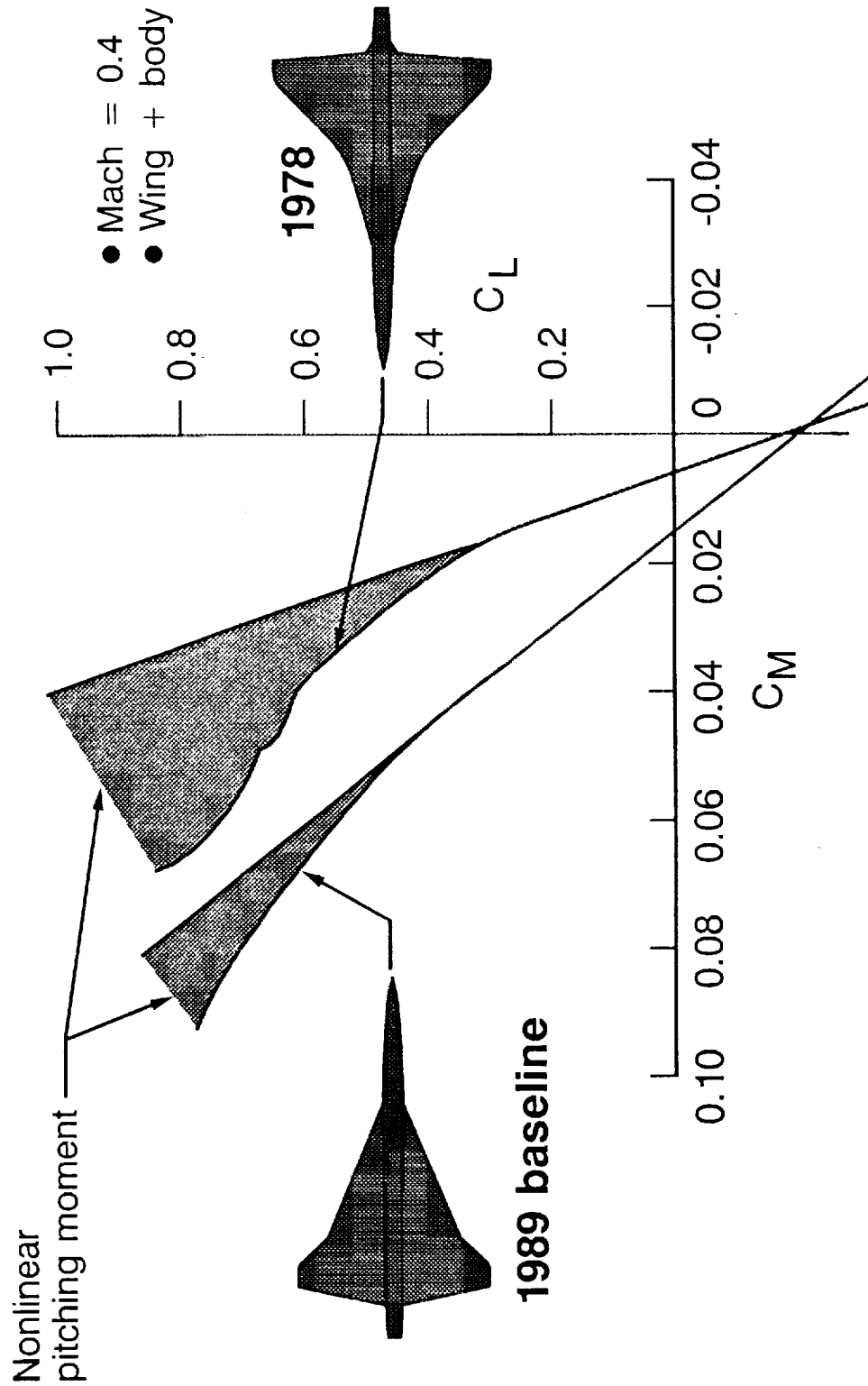


Boeing supersonic wind tunnel

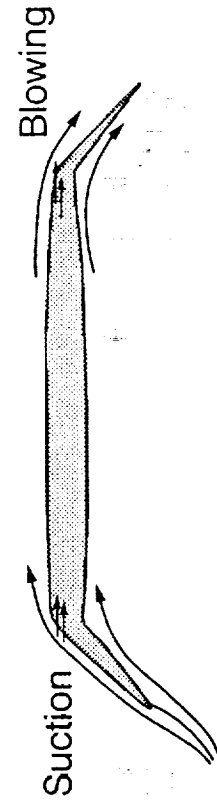
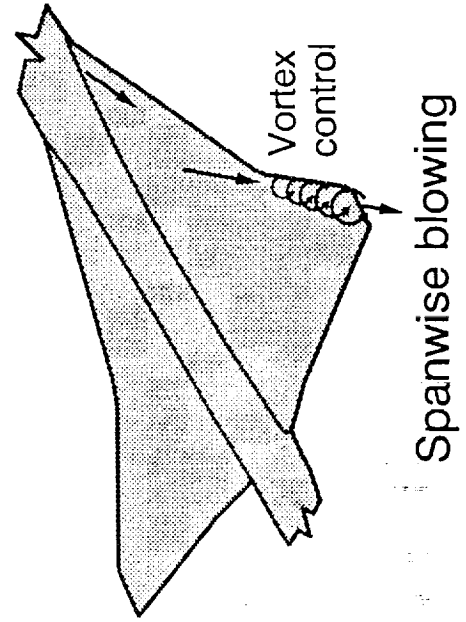
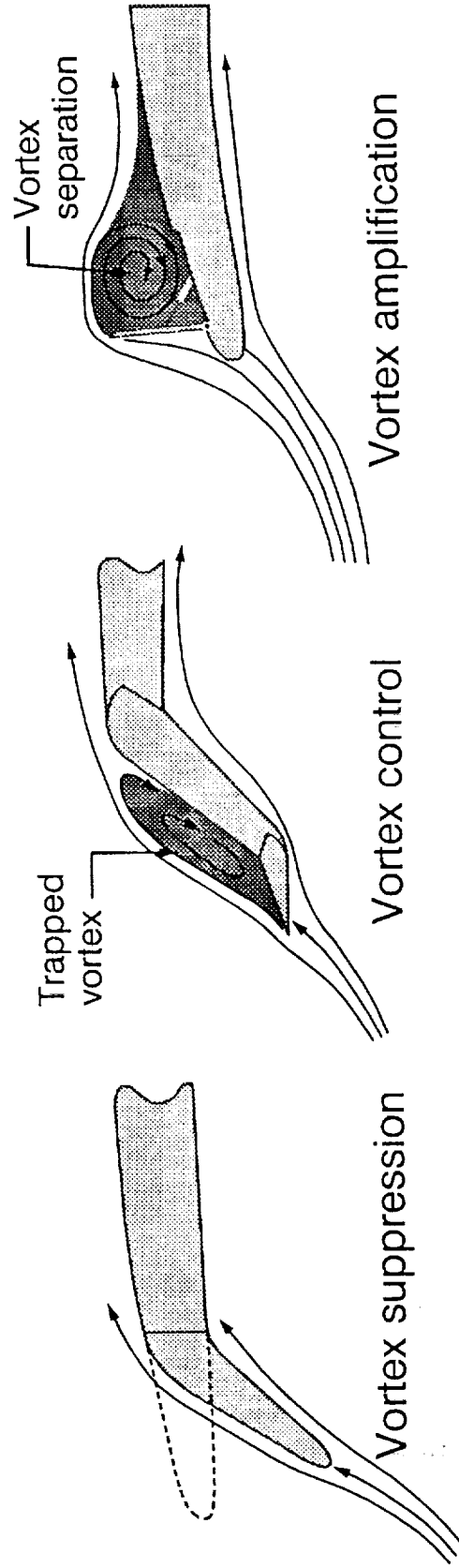


Test versus theory comparison

Pitching Moment

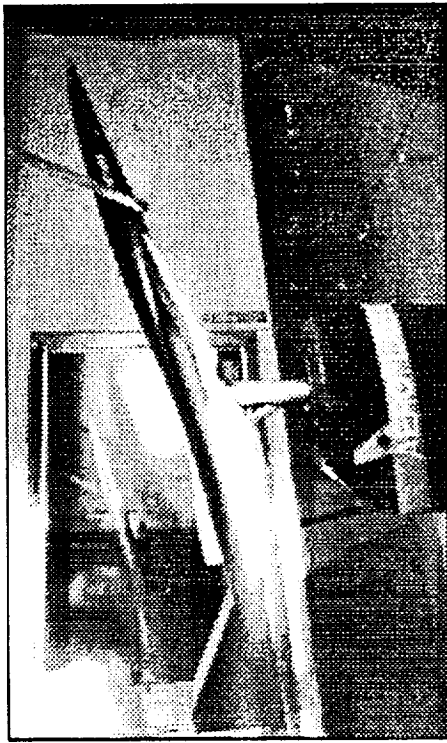


High-Lift System Concepts

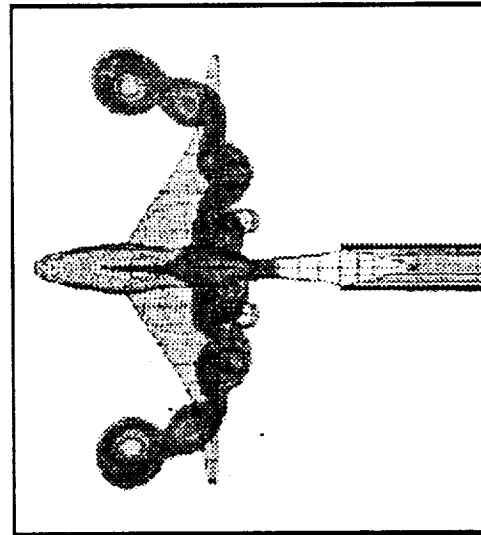


Boundary layer control

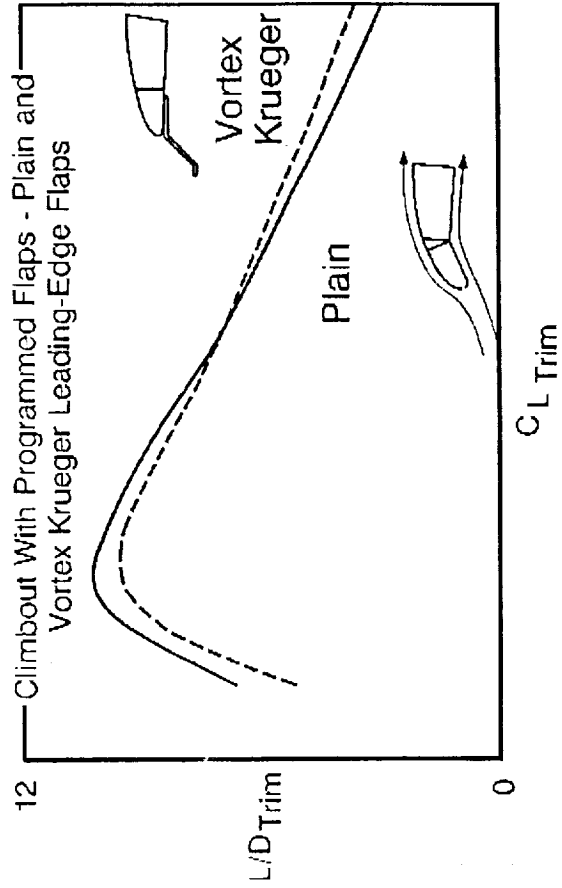
Vortex Krueger Flaps



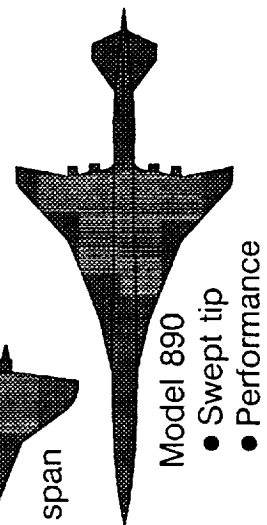
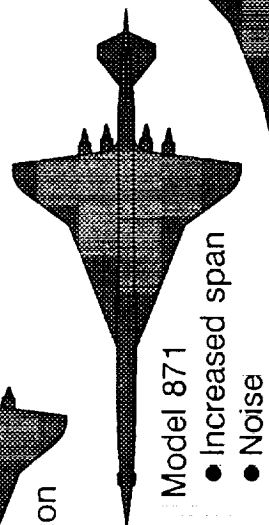
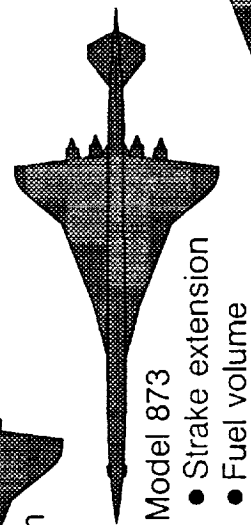
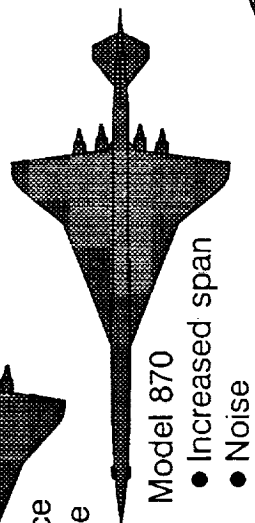
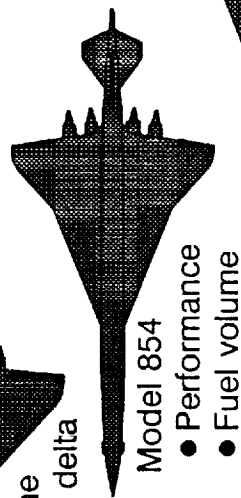
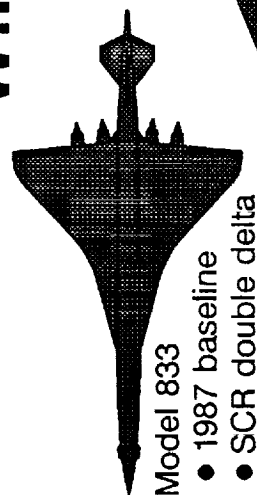
Vortex Krueger
Trapped Vortex



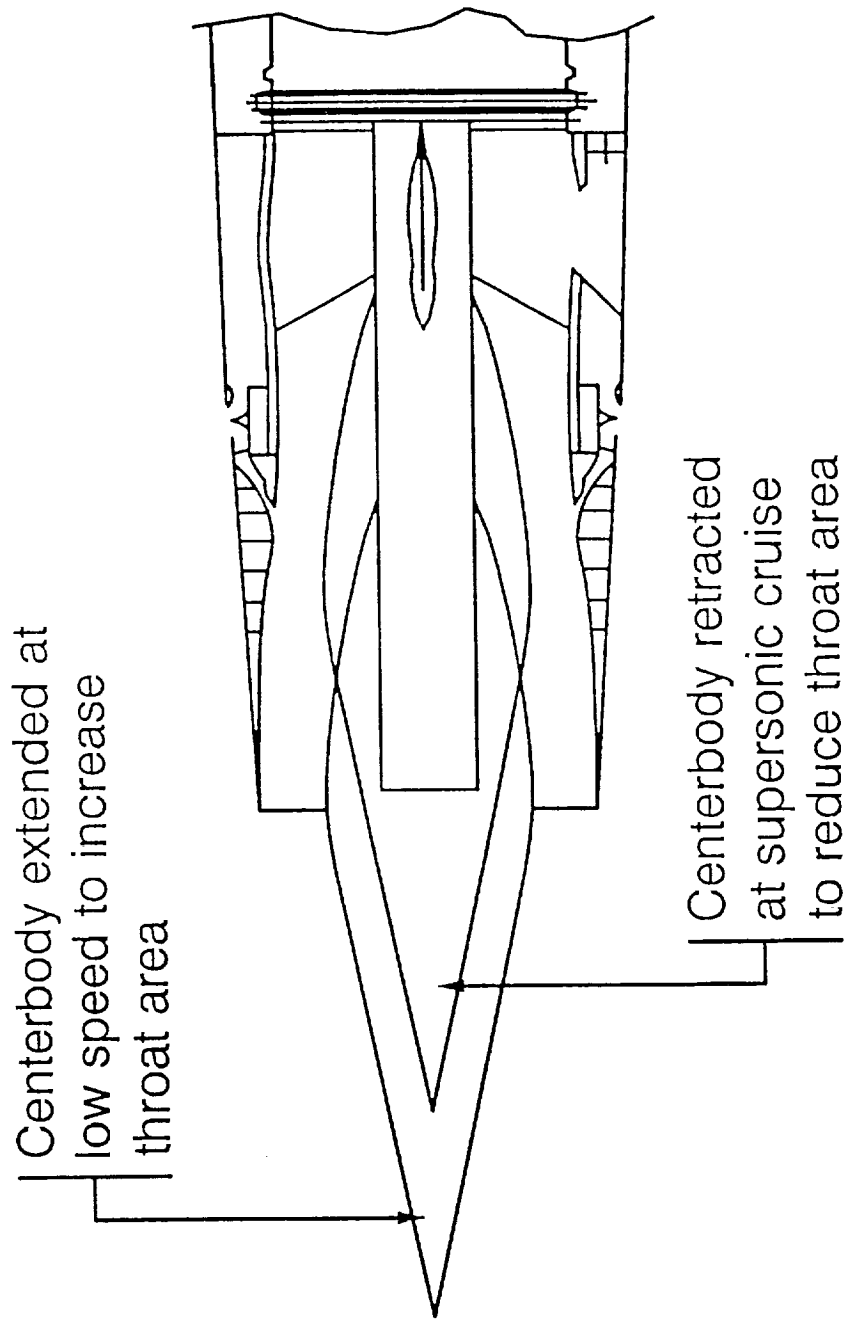
High L/D - Attached Flow



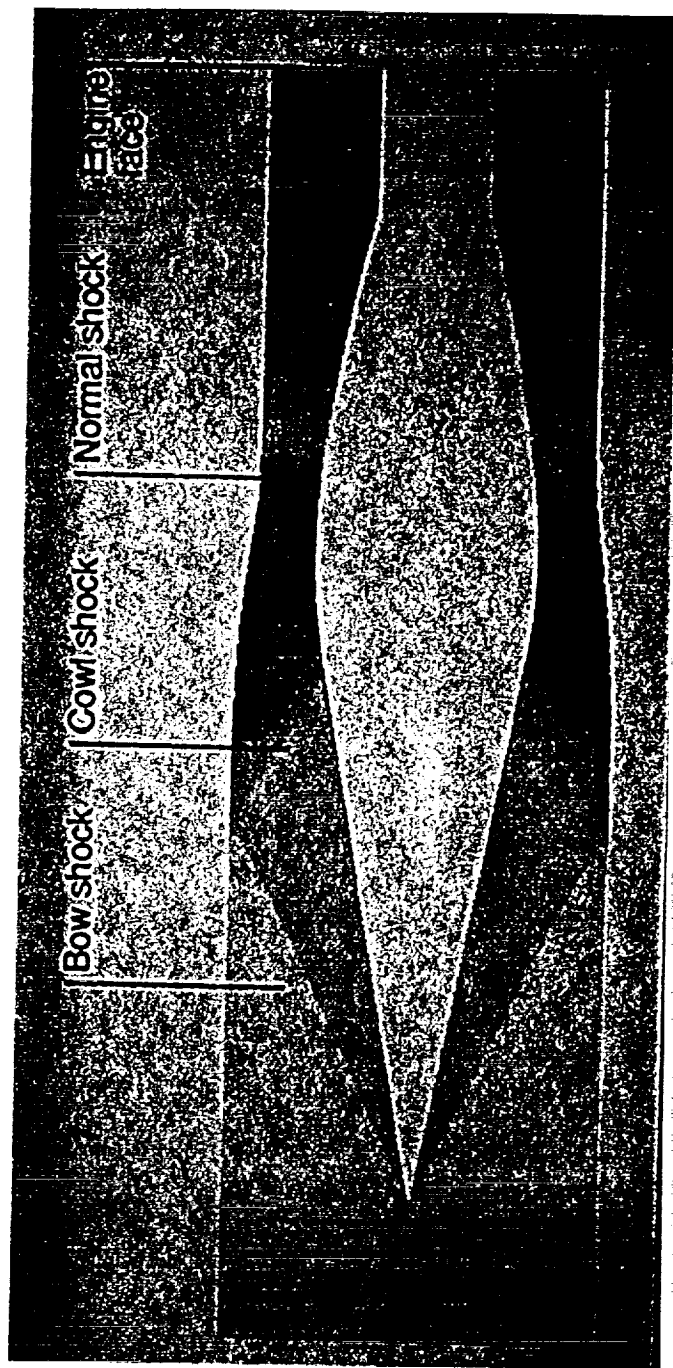
Wing Planform Evolution

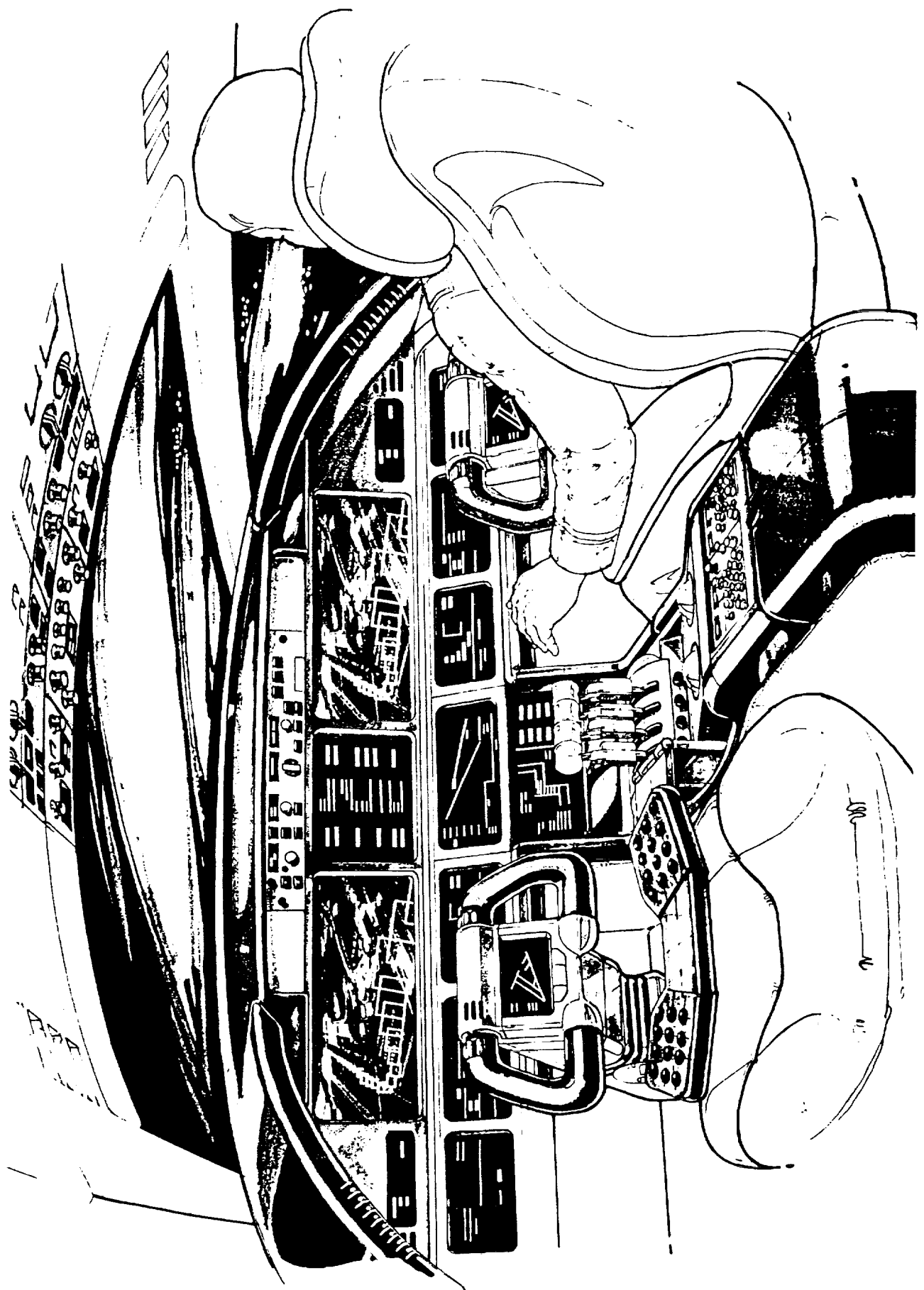


Variable Geometry Inlet Concept



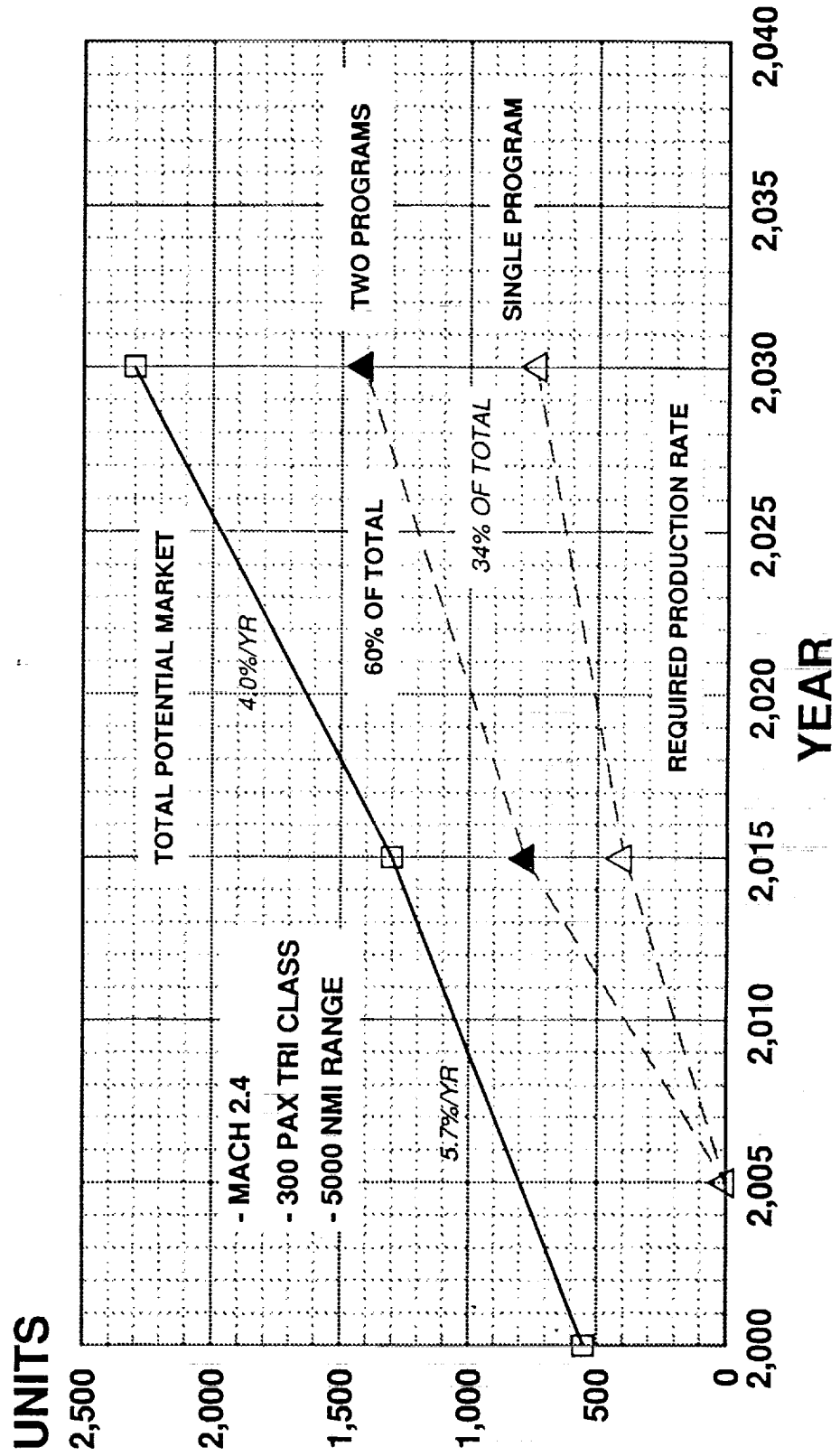
CFD Representation of the Inlet Operating at Mach 2.4



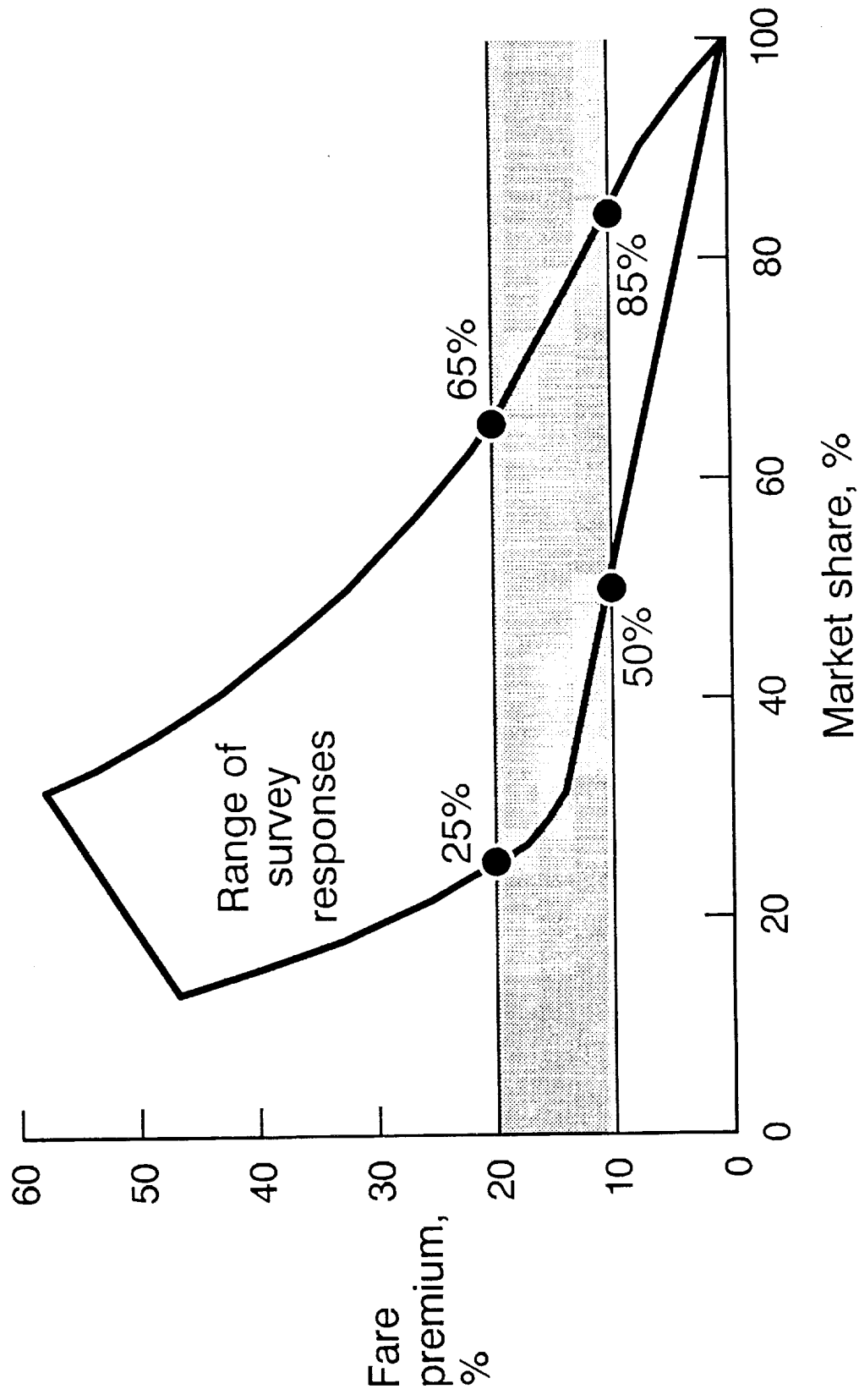


HSCT MARKET ESTIMATE

MINIMUM MARKET - SINGLE AND TWO SUCCESSFUL PROGRAMS

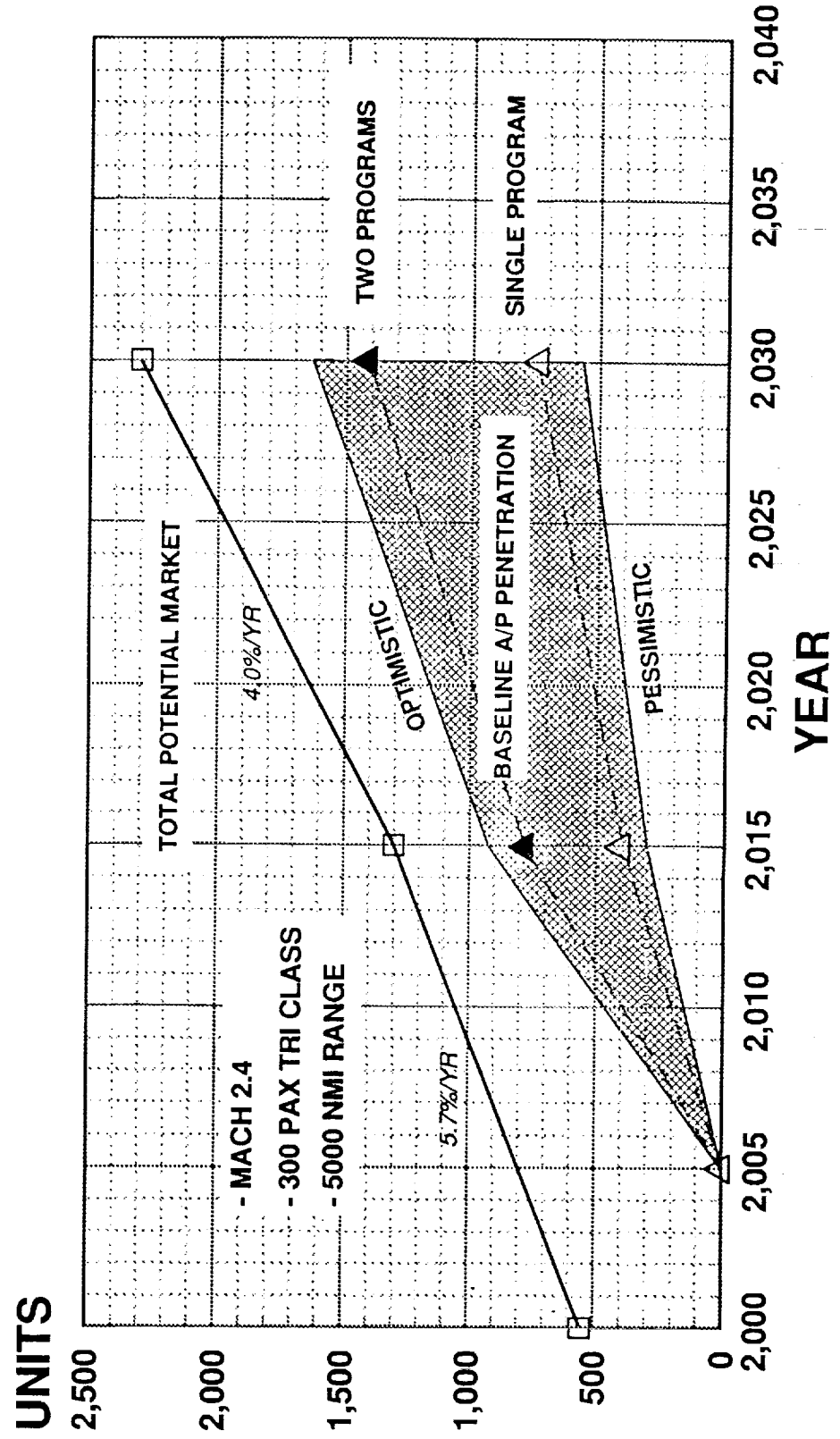


Passenger Willingness to Pay a Fare Premium

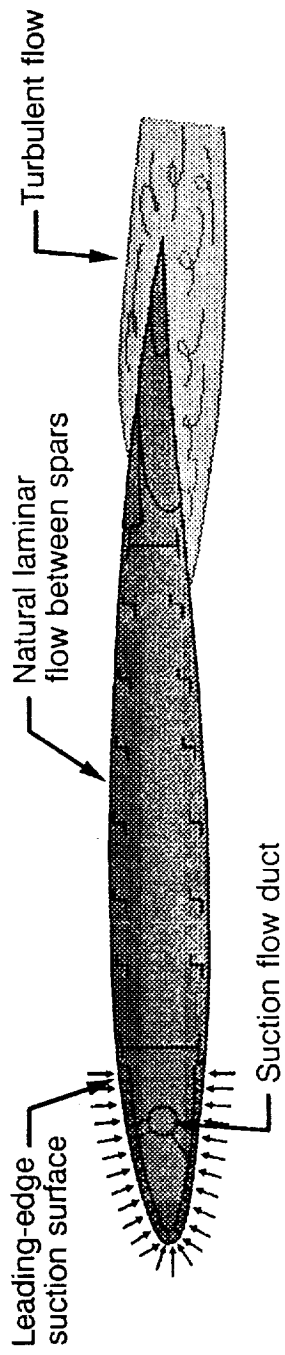


HSCT MARKET ESTIMATE

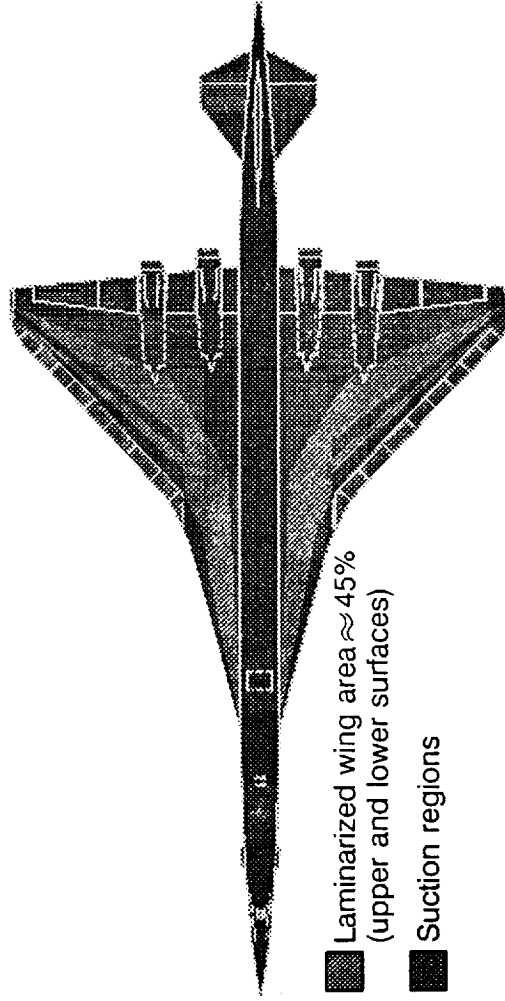
BASELINE HSCT MARKET PENETRATION



HSCT Laminar Flow Control Studies



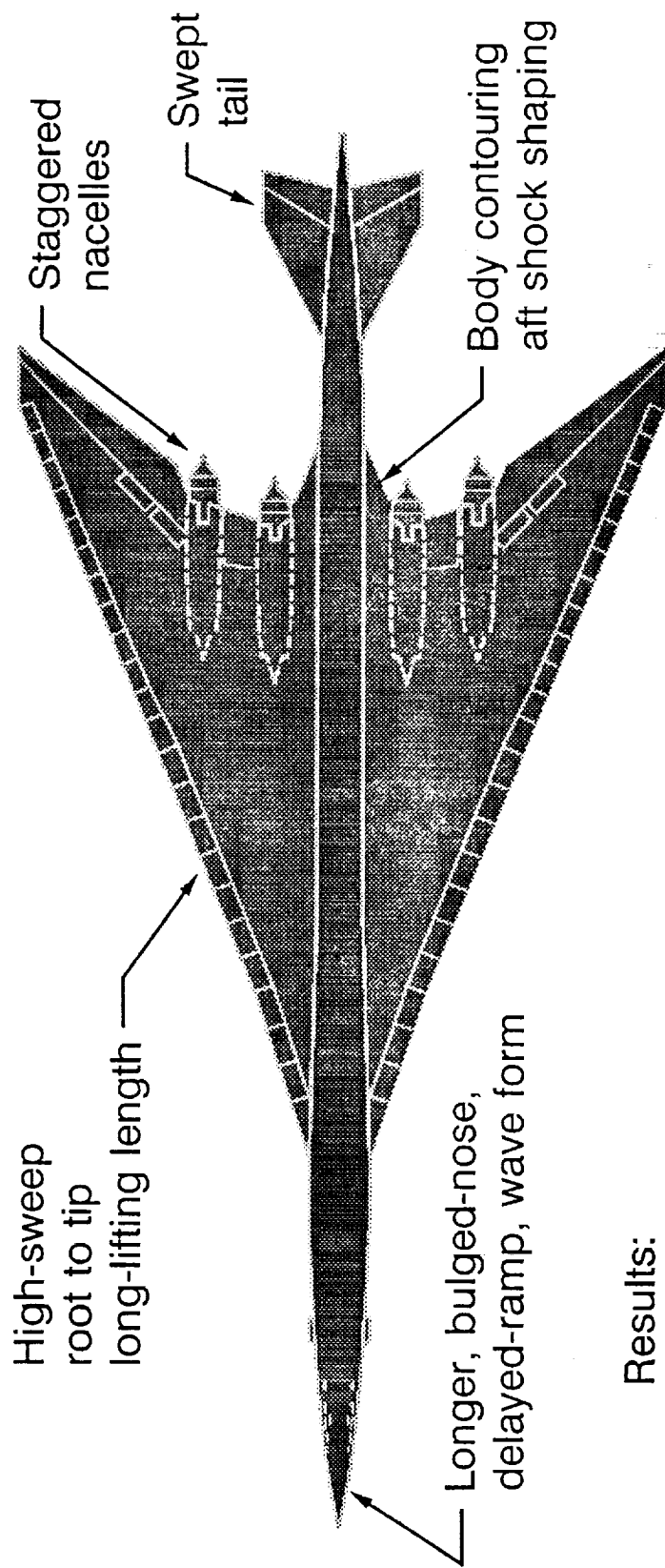
Airfoil section showing laminar flow control details



HSCT laminar flow control concept

BOEING PROPRIETARY

Low-Sonic-Boom Design Results

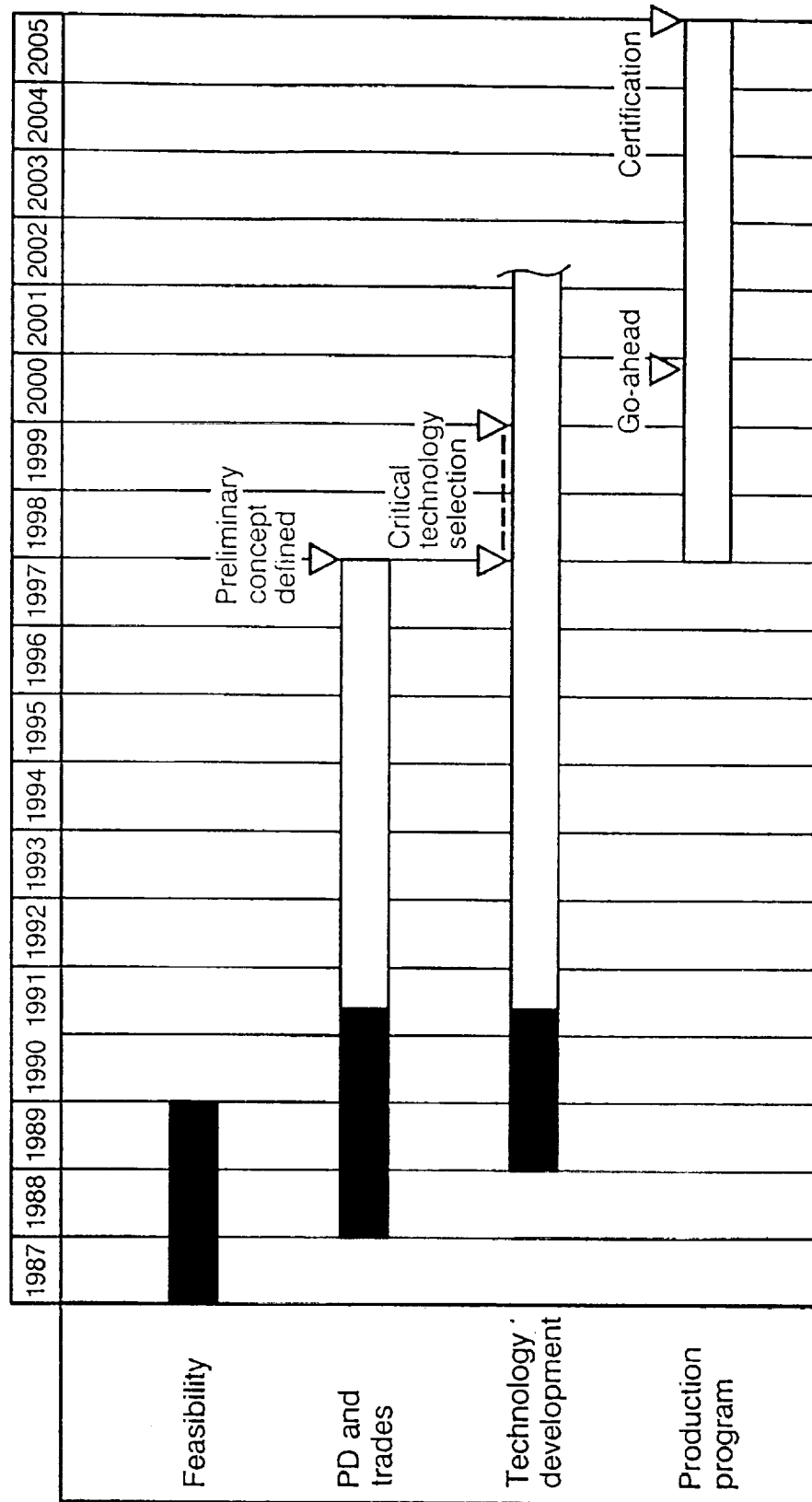


Results:

- Boom over pressure - 0.75 psf (base is 2.5 psf)
- Boom loudness - 71 dBA (base is 88 dBA)
- Gross weight penalty - + 2%
- Payload penalty - -42 passenger (-15%)

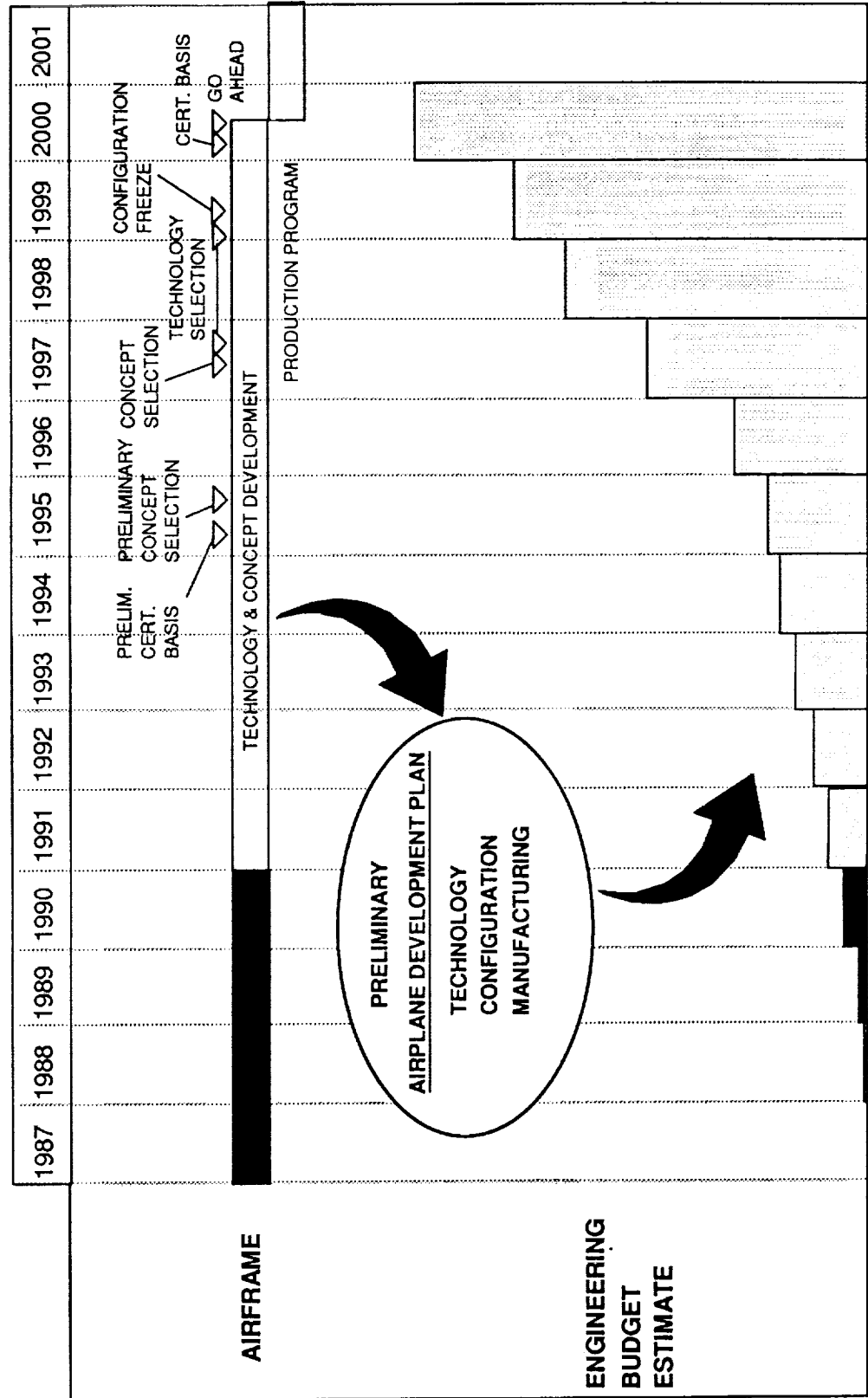
BOEING PROPRIETARY

HSCT Planning Schedule



HSCT TECHNOLOGY DEVELOPMENT PLAN

TECHNOLOGY AND CONFIGURATION DEVELOPMENT MILESTONES



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BOEING VIEW OF HSR PHASE I

- NASA HSR PHASE I PROGRAM ON TARGET
 - GOALS, OBJECTIVES & TECHNICAL PLAN FORMULATED VERY WELL
 - EXCELLENT START TOWARD PROGRAM GOALS
- NEED TO MAINTAIN FOCUS
- KEY TO SUCCESS OF PHASE I WILL BE TIMELY DELIVERABLES

a-2.

BOEING VIEW OF HSR PHASE II

- **HSR PHASE II PROGRAM ESSENTIAL FOR DEVELOPMENT OF ENABLING AND HIGH RISK, HIGH PAYOFF EMERGING TECHNOLOGIES**
- **AGREE WITH PRIORITIES AND RELATIVE FUNDING LEVELS**
- **A MORE DETAILED PHASE II NASA HSR TECHNOLOGY DEVELOPMENT PLAN NEEDS TO BE DEVELOPED WHICH:**
 - **USES PRESENT HSR PHASE II PLAN AS A BASE**
 - **IS INTEGRATED WITH INDUSTRY PRODUCT & TECHNOLOGY DEVELOPMENT PLANS**
 - **IS CENTRALLY MANAGED WITH BUY-IN BY THE NASA CENTERS**
 - **IS NOT CONSTRAINED BY NASA MANPOWER**

Session I. Plenary Session

mit

Update on Douglas' High-Speed Civil Transport Studies
Bruce L. Bunin, Douglas Aircraft Company

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Update on Douglas' High-Speed Civil Transport Studies

**Bruce L. Bunin
Business Unit Manager
Advanced Commercial Programs**

**Presented to:
First Annual High-Speed Research Workshop
Williamsburg, Virginia
14 May 1991**

INTRODUCTION

This report presents a summary of high speed civil transport (HSCT) studies underway at the Douglas Aircraft Company (DAC), a division of McDonnell Douglas Corporation (MDC). The report begins with a brief review of experience at MDC with design and development of advanced supersonic transport concepts and associated technology. A review is then presented of past NASA funded contract research studies focused on selection of appropriate concepts for high speed civil transport aircraft to be introduced in the year 2000 time frame for commercial service. Follow-on activities to those studies are then presented which have been conducted under DAC independent research studies as well as under further NASA funded efforts. The report discusses design mach number selections and associated baseline design missions, forecasted passenger traffic and associated supersonic fleet sizes, and then proceeds into a discussion of individual issues related either to environmental acceptability or overall technology requirements in order to achieve the required economic viability of the program. The report concludes with a summary of current and future plans and activities.

***T**opics Covered*

Background

Current Studies

Douglas Approach

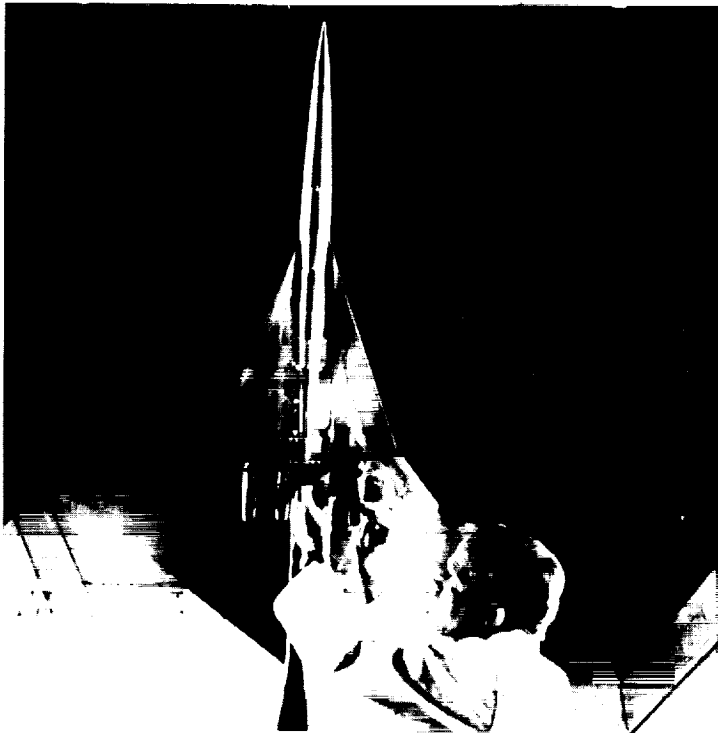
Environmental Issues

Key Technologies

Plans

DOUGLAS BACKGROUND

DAC's experience in the Supersonic Commercial Aircraft Studies spans more than 30 years, including the SST and SCAR studies in the 1960's. A significant amount of experience was gained in the 1970's by DAC in participating with the NASA AST program and related technology studies such as this Douglas/NASA 1.5 percent scale wind tunnel test illustrated below.



NASA DAC HSCT STUDIES

In 1986 MDC began studying HSCT concepts under contract to NASA Langley Research Center. The studies began with an open minded approach to determine the viability of future high speed commercial transport concepts. A wide speed or mach range was considered, with configuration studies conducted between the range of low supersonic speeds to hypersonic aircraft cruising in the range of Mach 10-12. These concepts were compared to a baseline subsonic long range transport with performance levels envisioned beyond the year 2000. A key aspect of these studies were considerations associated with environmental compatibility, primarily in the areas of noise, emissions and sonic boom. These studies were intended to determine the most viable concepts which would then warrant additional studies. The studies were not only technical in nature, but included extensive market evaluations and economic analyses intended to consider the viability of each concept as a commercial product. The end result of these studies would then enable the identification of key technologies requiring further development.

***O** NASA-Douglas HSCT Studies bjectives*

Examine Wide Speed/Mach Range

Address Environmental Compatibility

Focus Opportunities

Qualify Market Potential

Determine Economic Viability

Identify Technology Drivers

DESIGN GOALS WERE ESTABLISHED
FOR
NASA FUNDED STUDY

For the purpose of these studies, target values for design range, number of passengers, and economic performance, were established. Goals for environmental compatibility were also established. MDC proposed that airport noise levels within FAR Part 36 Stage 3 limits would be acceptable. The emissions goals were established on the basis of total allowable mass of NO_x. Aggressive goals were also set for levels of overpressure and perceived noise levels associated with low sonic boom configurations with the possibility of supersonic overland flight in mind. These goals were associated with a projected IOC between the years 2000 and 2010.

***D**esign Goals Were Established for NASA-Funded Study*

Design Range: 6,500 Nautical Miles

Passengers: 300

Environment Goals:

- Noise - FAR Part 36 Stage 3 Limits
- Emissions - EINO_x = 5-10 lb/1,000 lb
- Sonic Boom - 0.6 psf and 9 PLdB
(Fly Supersonic Overland)

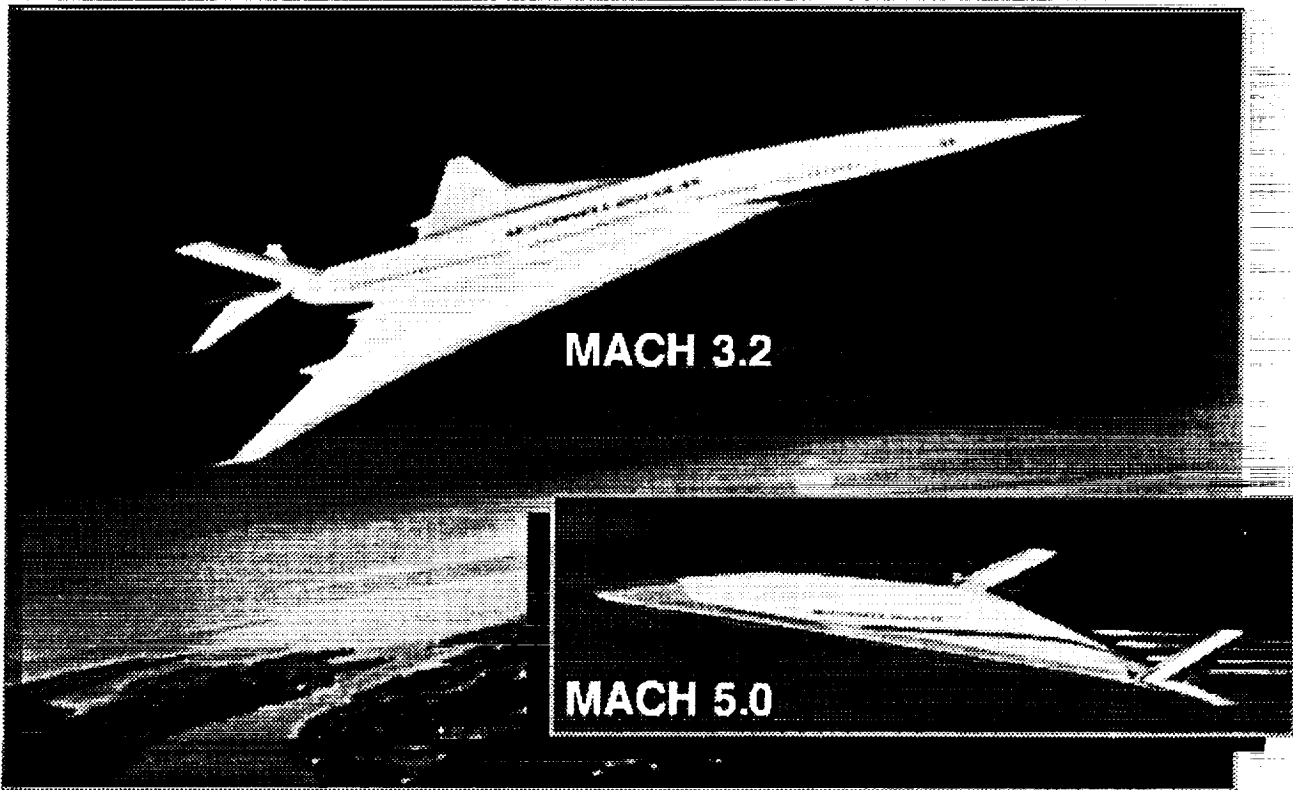
Economics: Profitable at 10-Percent Fare Premium

IOC: Year 2000-2010

HIGH SPEED CIVIL TRANSPORT

The results of these studies concluded that two HSCT concepts were superior in overall aircraft worth and warranted further studies. These were a supersonic aircraft cruising at Mach 3.2 and with conventional JP fuel, and a hypersonic aircraft cruising at Mach 5.0 with methane fuel. These aircraft concepts were carried into further systems studies and evaluations.

HIGH-SPEED CIVIL TRANSPORT



DAC HSCT APPROACH

The Mach 3.2 and Mach 5.0 high speed aircraft concepts were carried into further studies under NASA contract as well as Douglas Aircraft Company IRAD. The overall approach to these studies is described in the adjacent Figure. Generally, a goal of 300 passengers and 6500 nautical miles was maintained. As further studies eliminated the near term viability of hypersonic concepts, the viable speed range was reduced to mach numbers ranging from 1.6 to 3.2. Douglas HSCT concepts continued to be studied within that Mach range. Compatibility with existing airports, the subsonic airspace, and the overall environment were important criteria as well. A fare premium of 10 percent was considered to be a reasonable goal with respect to airline ticket price, and a typical subsonic market passenger mix was assumed.

H *Douglas Aircraft Company* ***HSCT Approach***

MD-11 Payload and Range

Two to Four Times Faster

Profitable to Airlines

- Minimum Ticket Premium
- "Subsonic" Market Passenger Mix

Compatible With Existing Airport Runways

Compatible With Subsonic Airspace

Compatible Environmentally

DAC HSCT DESIGN EFFORTS WILL FOCUS ON LOWER SPEED CONCEPTS

As design studies progressed at DAC within the speed range discussed on the previous chart, it became more and more obvious to the Douglas team that a Mach 3.2 HSCT was high risk both in terms of technology readiness to support a 2005 certification date, and in terms of its effect on the atmosphere when compared to other aircraft concepts. For this reason, Douglas studies were focused within a speed range of Mach 1.6 to 2.4 in 1990. We have conducted studies at Mach 2.2, for which we have an extensive data base from advanced supersonic transport studies conducted in the 1970's, and are also in the process of conducting design studies at Mach 2.4. The lower speed concepts under evaluation are considered to be alternative approaches from our Mach 2.2/2.4 baseline designs. A Mach 1.6 aircraft, while having less productivity and marketability than the higher speed concept, has other advantages in terms of lower engine emissions impact and lower development and production costs. Douglas continues to develop concepts for low sonic boom designs, and our most recent studies have resulted in a Mach number selection of 1.8.

***T**he Douglas Aircraft Company The HSCT Design Efforts Will Focus on Lower Speed Concepts*

Cruise Mach No.	Advantages	Disadvantages
1.6/1.8	Lowest Engine Emissions Impact Lowest Development and Production Cost and Risk Possible Low-Boom Solution	Lowest Productivity Marketability
2.2/2.4	Existing Data Base Moderate Productivity Technology Readiness Achievable With Timely Investment	Higher Development Cost and Risk Than Mach 1.6 Low-Boom Solutions May Require Multiple Cruise Mach Numbers
3.2	Highest Productivity Minimum Travel Time	High Technical Risk for 1998 TAD Worst Case for Emissions Low-Boom Solutions May Require Multiple Cruise Mach Numbers

BASELINE DESIGN MISSION AND CRUISE MACH NUMBERS
SELECTED TO REDUCE PROGRAM RISK AND IMPROVE ECONOMICS

As we proceeded with detailed design studies for a baseline aircraft concepts and associated supersonic network analyses, it was determined that overall aircraft worth is maximized at a somewhat lower design range than our previous long range goals. For that reason, we have revised our baseline design range to 5500 nautical miles while still conducting trade studies in the range of 5000 to 6500 nautical miles. Our baseline payload remains 300 passenger, and the analysis of our global supersonic network results in an average overland distance of 25 percent. As stated on the previous page, our baseline cruise Mach number combinations are 2.4 overwater/0.95 overland, 1.6 overwater/0.95 overland and 1.8 overwater and overland for the low sonic boom design.

Baseline Design Mission and Cruise Mach Numbers Selected to Reduce Program Risk and Improve Economics

Baseline Design Mission

- 5,500 Nautical Miles
- 300 Passengers
- 25-Percent Overland

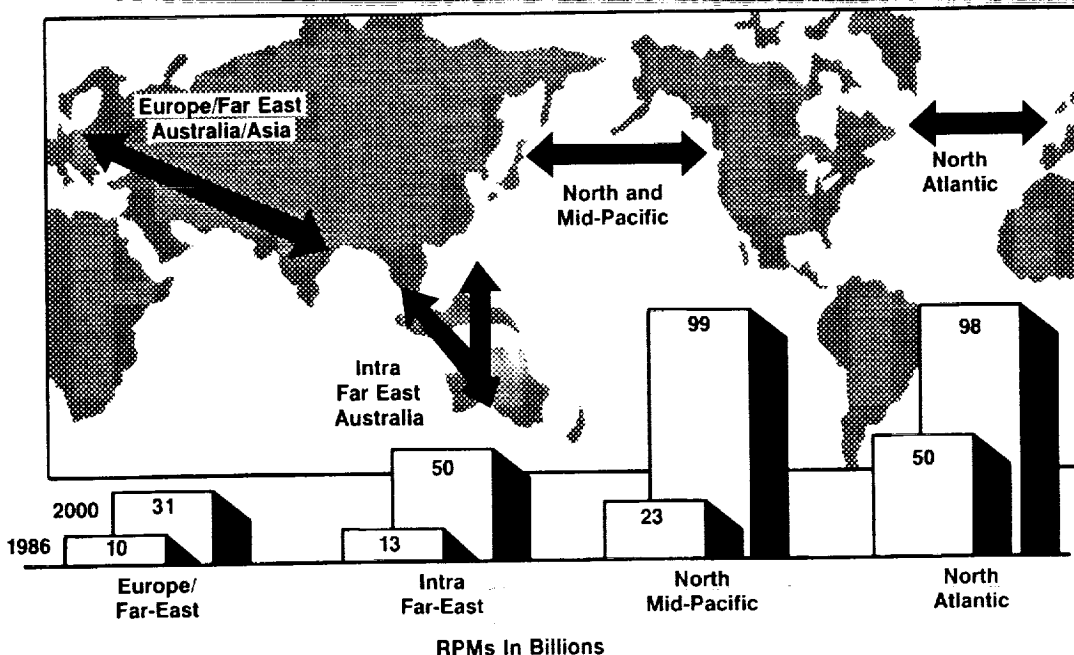
Cruise Mach Number

- 2.4/0.95 (Baseline)
- 1.6/0.95 (Low Atmospheric Impact)
- 1.8/1.8 (Low Sonic Boom)

INTERNATIONAL PASSENGER TRAFFIC -
MAJOR REGIONS -
85-90 PERCENT OF TOTAL

In order to insure that division of program economic viability is maintained, we continually revisit our forecast for long range passenger traffic beyond the turn of the century. The attached figures shows passenger traffic divided up among 4 major regions with values in billions of passenger revenue miles for the year 1986 and projected values for the year 2000. This figure projects a dramatic increase in traffic in both the intra Far East and North Mid Pacific regions. If we project the traffic in these regions out to the year 2010 or 2020, we would expect to see continued growth in the North Mid Pacific and North Atlantic regions, at approximately the same rate in each region as the North Mid Pacific region matures. These predictions maintain our confidence that long range passenger traffic beyond the turn of the century support a sufficiently large number of high civil transport aircraft to insure economic viability for the manufacturer.

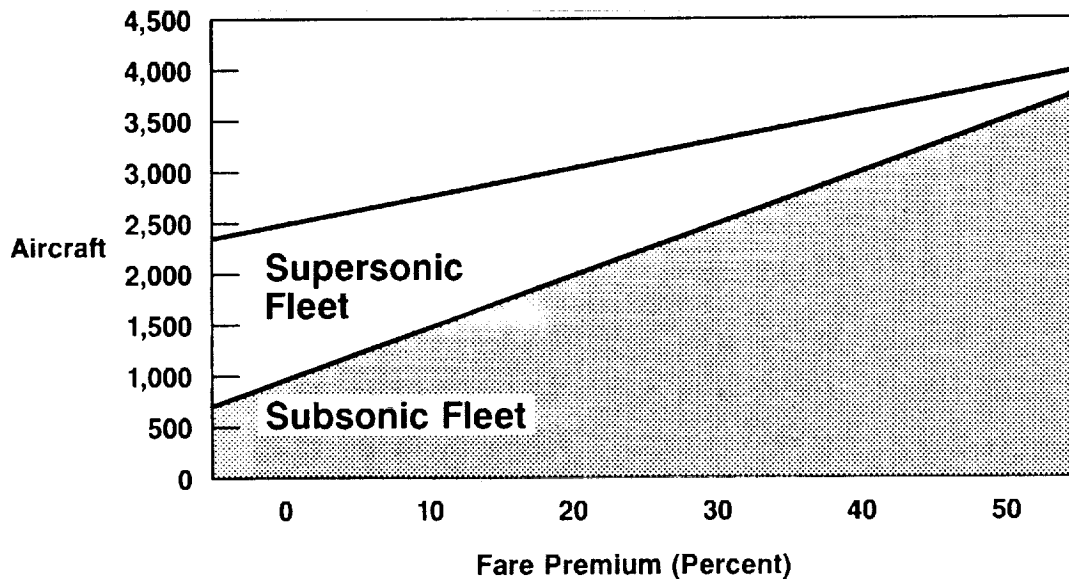
International Passenger Traffic - Major Regions - 85-90 Percent of Total



FLEET REQUIREMENTS BY THE YEAR 2025

Given a set of long range passenger traffic predictions, we may then project the amount of supersonic aircraft required to meet traffic demand as a function of fare premium shown as a percentage above conventional subsonic fares. The chart indicates that at a fare premium of 10 percent for a fleet size of greater than 1000 is envisioned.

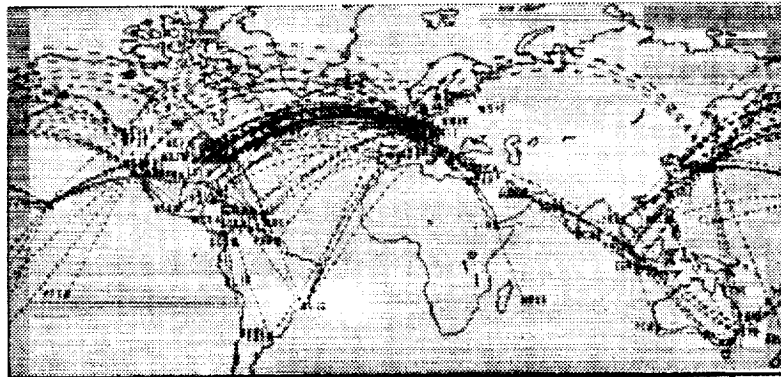
Fleet Requirements by Year 2025 *Impact of Fare Premium on Supersonic and Subsonic Fleet Mix*



250 CITY PAIR SUPERSONIC NETWORK

Extensive analysis of supersonic network associated with primary long range city pairs has been completed. These analyses are used to determine the overland distances for supersonic routes and to examine alternative route structure such as supersonic overland corridors or route diversions. The results of these studies for the 250 city pairs is used indicated and average percentage overland of 25.9 percent for diverted routes which maximize the overwater segment of flight.

A *250 City-Pair Supersonic Network Used to Determine Overland Distance and Alternative Route Structures*

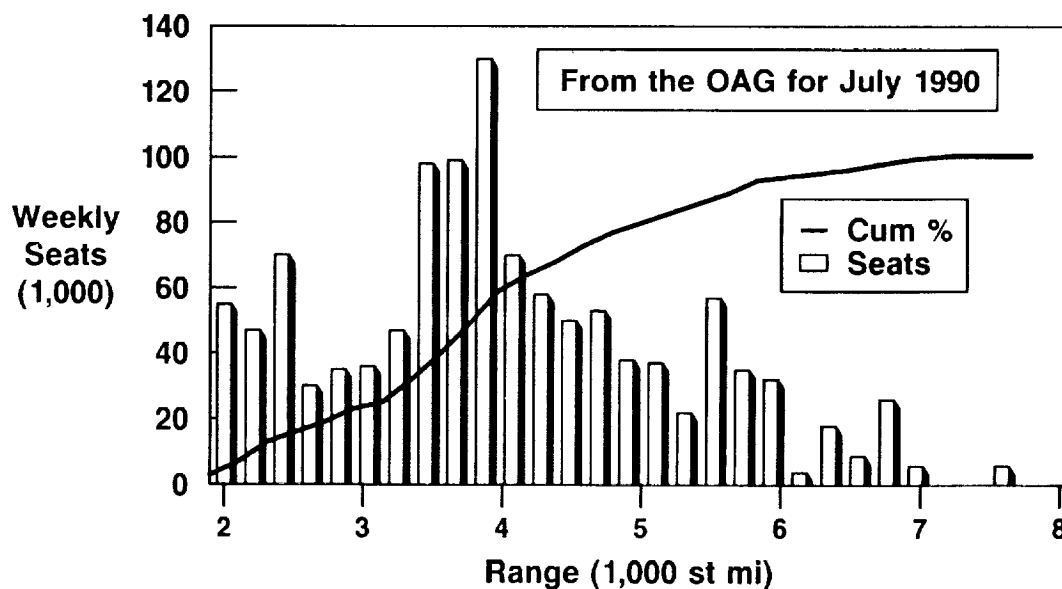


Great Circle Distance	891,809 st mi	Diverted Distance	932,618 st mi (Increase 4.5%)
Overland Distance	414,266 st mi	Overland Distance	241,813 st mi (Reduction 41%)
Percent Overland	46.5%	Percent Overland	25.9%

HIGH SPEED CIVIL TRANSPORT
TOP 250 AIRPORT PAIRS BY SEATS OFFERED

Studies are also conducted to examine the selection process for supersonic networks with respect to maximum design range. The attached chart plots weekly seats in thousands against the range frequencies for the top 250 city pairs by seats offered and indicates the associated range of these city pairs in statute miles. Using these data, it was determined that a design range of roughly 6300 statute miles (5500 nautical miles) would maximize aircraft worth at a cruise Mach number of 2.4. These types of studies are continually updated based on the most recent traffic forecasts and various combination of city pairs.

T *High-Speed Civil Transport* *Top 250 Airport Pairs by Seats Offered*



MDC EFFORTS ARE FOCUSED ON VALIDATING RESULTS OF PRELIMINARY STUDIES
AND REDUCING PROGRAM RISKS

The near term objective of DAC HSCT studies is to develop an understanding of and solutions to key environmental constraints in the area of noise, emissions and sonic boom. Additionally baseline design concepts will continue to be refined and assessed in terms of their economic viability in environmental compatibility. Long lead technology development efforts have been initiated in selected areas.

***MDC
Efforts Focus on Validating Results
and Reducing Program Risk***

**Develop Understanding of and Solutions to
Environmental Constraints**

**Refine Design Concepts to Ensure Selection of the
Most Viable Product**

- Cruise Mach Number
- Range
- Payload
- Technology
- IOC

ENVIRONMENTAL ACCEPTABILITY DESIGN GOALS

Our initial goals for environmental acceptability are shown on the attached chart. With respect to emissions, an ozone depletion level of not greater than 1 percent is generally acceptable as a reasonable goal for a future fleet of HSCT's. The question here is with respect to the ability or accuracy of atmospheric models to predict these depletion levels based on a given amount of combustion products produced by a fleet of aircraft. Current subsonic FAR Part 36, Stage 3 noise limits form the basis for airport noise for HSCT airport noise limits. In addition, airport and climb to cruise noise levels must be acceptable from a community noise standpoint. Finally, aggressive goals are established for shock wave overpressure and associated loudness levels for sonic boom minimization levels. The goal of 90 PLdB was our initial guess at a possible level of human acceptance for supersonic overland flight.

***E**nviro**n**mental Acceptability Design Goals*

Engine Emissions

- **No Adverse Change in Ozone Concentration**

Certification/Community Noise

- **Meet Current Subsonic FAR Part 36, Stage 3, and ICAO Annex 16, Chapter 3, Noise Limits**
- **Achieve Airport and Climb-to-Cruise Noise for Community Noise Acceptability**

Supersonic Overland

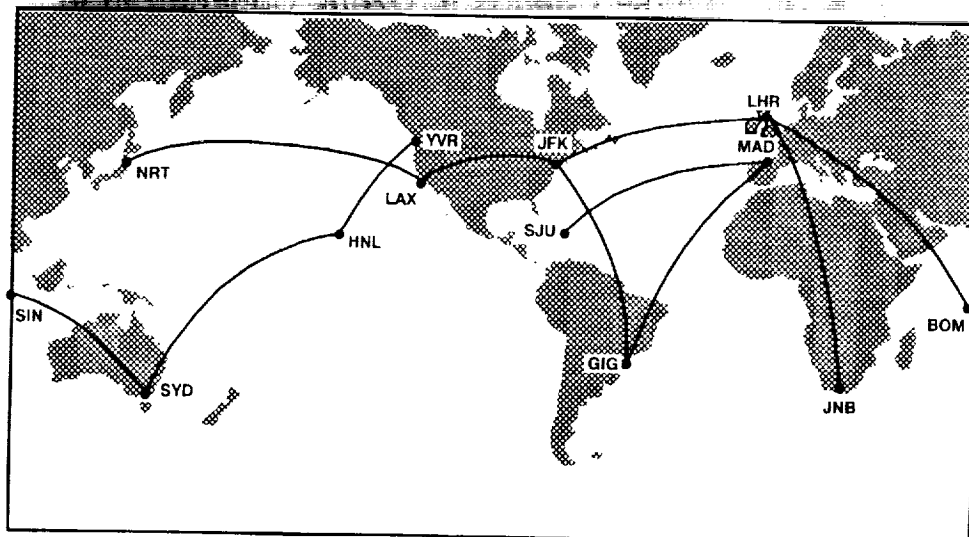
- **Minimal Environmental Impact and Acceptable Human Response**

HSCT EMISSIONS ARE PRIMARILY AFFECTED BY THREE PARAMETERS

Of the three primary issues related to environmental compatibility of a fleet of HSCT's, the issue of aircraft emissions and the associated effects on the atmosphere remain the most uncertain. The key technology associated with reducing emissions for subsonic as well as supersonic aircraft is the development of low emissions (low NO_x) combustors. The engine manufacturers in conjunction with NASA have established plans to develop the required technologies for low NO_x combustors over the next several years. From an airframe manufacturer standpoint, any incremental improvement in aircraft performance (drag reduction, weight reduction, etc.) will reduce the amount of emissions left in the atmosphere. Beyond that, the parameters that control atmospheric effects are the aircraft cruise altitude and mach number, and the route structure of the fleet. At a lower level of detail, the density of flights within that route structure, the location (latitude and longitude) of the flights, and the seasonality or time of year, all have a significant effect on atmospheric effects.

HSCT ***Emissions Are Primarily*** ***Affected by Three Parameters***

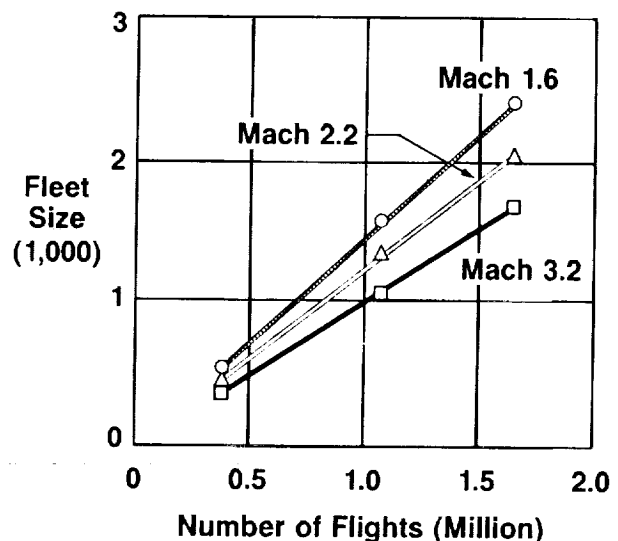
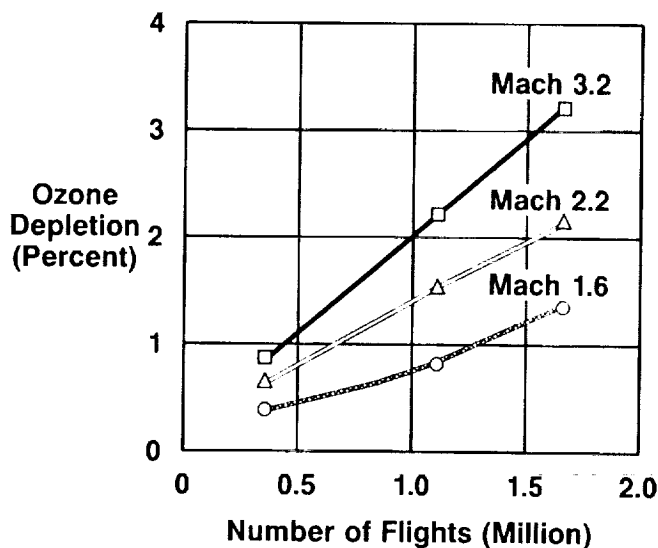
- Propulsion System Combustion Products
- Aircraft Altitude/Mach Number
- Route Structure



ATMOSPHERIC STUDIES PREDICT THE EFFECTS OF CRUISE ALTITUDE AND FLEET SIZE ON OZONE DEPLETION

Douglas has conducted studies in conjunction with atmospheric modelers in an attempt to gain a preliminary understanding of the levels of ozone depletion that could result from a fleet of HSCT's. The lower of the two charts shows three different fleet sizes for three different HSCT aircraft such that the total number of flights over a fixed period of years remains constant. The upper curve shows the predicted levels of ozone depletion for each scenario using a currently available atmospheric model. It should be noted that the depletion levels are percentage reductions in the ozone layer at an equilibrium state, not a recurring reduction over some period of time. This model predicts that both the fleet size and the cruise altitude have a strong influence on the level of ozone depletion. The lower predicted levels of depletion for the Mach 1.6 aircraft is the primary reason for Douglas' decision to continue evaluating that concept in our matrix of configurations.

Atmospheric Studies Predict the Effects of Cruise Altitude and Fleet Size on Ozone Depletion



Note: Assumes Successful Low-Emissions Combustor Development

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TECHNOLOGY DEVELOPMENT REQUIRED TO MEET STAGE 3 NOISE LIMITS

Our current design goals for aircraft noise are to achieve compatibility with current stage 3 limits. Engine manufacturers are currently pursuing various propulsion system concepts which appear promising in terms of meeting these objectives. The most promising candidates based on Douglas assessments are the turbine bypass engine with a mixer/ejector, and the FLADE engine cycle with a suppressor/fluid shield. NASA and the engine companies will proceed with the development and evaluation of these concepts over the next several years.

In addition to reductions in engine noise, the development of efficient high-lift systems using leading and trailing edge devices will also be required to ensure airport noise limits are met. Both low speed lift characteristics and lift to drag ratios (L/D) can be improved through the use of high-lift concepts. Improvements in lift characteristics will result in reduced takeoff field length, while low speed L/D improvements will result in a higher flight profile and a lower cutback thrust level, all contributing to noise reduction.

T ***Technology Development Required to Meet Stage 3 Noise Limits***

Promising Engine Candidates Are Emerging

- Turbine-Bypass Engine With Mixer/Ejector
- Flade With Suppressor/Fluid Shield

High-Lift Concepts Are Being Evaluated

- Low-Speed C_L and L/D Enhancements
- (C_L - Takeoff Field Legth)
- (L/D - Higher Flight Profile/Lower Cutback Thrust)

IMPACT OF HIGH LIFT TECHNOLOGY

The development of advanced high-lift systems will not only contribute to reducing aircraft nose levels, but will also provide benefits in overall aircraft performance and stability and control characteristics. High-lift enhancements will result in reduced thrust requirements for takeoff and climb, which will result in reduced engine size and weight, and reduced aircraft takeoff gross weight (TOGW). The use of leading edge devices for high-lift will also have a positive effect on longitudinal stability and lateral control effectiveness. These potential benefits warrant the aggressive development of high-lift system concepts, and studies involving the integration of such concepts into the basic design.

Impact of High-Lift Technology

Performance

TOGW, Engine Size, TOFL, and Approach Speed Are Significantly Affected by Efficient High-Lift Capability
High Subsonic L/D Reduces Fuel Burn (••Weight) in the Subsonic Climb and Cruise Mode

Noise

L/D Improvements Reduce Takeoff, Community, and Climb-to-Cruise Noise Levels

Stability and Control

Leading-Edge Devices Have a Positive Effect on Longitudinal Stability and Lateral Control Effectiveness

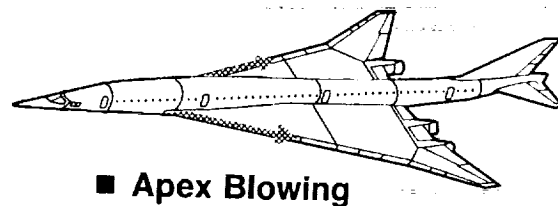
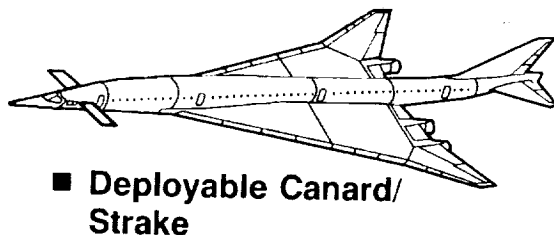
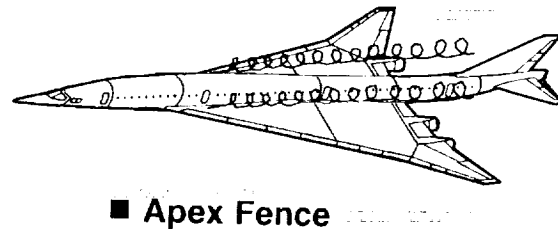
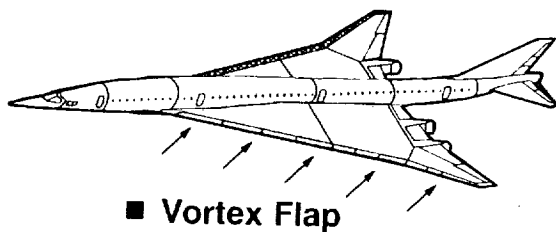
Integration

Must Be Integrated With LFC and Advanced Engine Nozzles

SOME INNOVATIVE HIGH-LIFT CONCEPTS

The attached chart illustrates some of the innovative high-lift concepts currently being evaluated by Douglas for further development. The use of a vortex flap, an apex fence, deployable canards or strakes, or apex blowing are all viable concepts for improving the high-lift characteristics of an HSCT. These concepts will be studied from both a performance and design integration standpoint, with the most promising concept or concepts carried forward for further development.

Some Innovative High-Lift Concepts



AST LOW SPEED WIND TUNNEL MODEL

Douglas has a cooperative effort in place with NASA Langley to conduct wind tunnel testing of candidate high-lift concepts using the existing ten percent scale model developed by Douglas and NASA under the Advanced Supersonic Transport (AST) program in the 1970's. NASA will conduct high-lift development tests using this model in the 30' x 60' low-speed wind tunnel. Testing is planned to begin in June of this year.



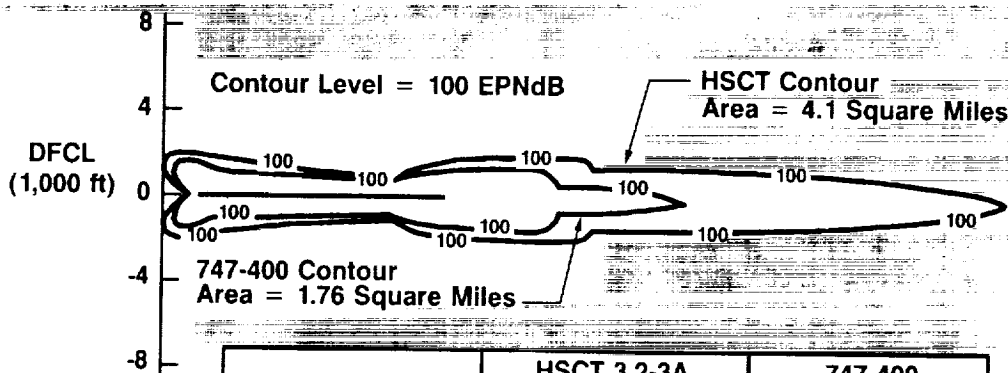
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COMMUNITY NOISE ISSUES MUST ALSO BE ADDRESSED

In addition to airport noise considerations, the impact of an HSCT on community noise must also be addressed. The attached plot compares the takeoff noise contours for a 747-400 and the predicted contour for a candidate HSCT configuration. This comparison shows that while both concepts are within stage 3 limits, the HSCT concept produces significantly more noise down range as compared to a typical subsonic stage 3 aircraft.

Community Noise Issues Must Also Be Addressed

Airport Noise Contour Study - HSCT Versus 747-400

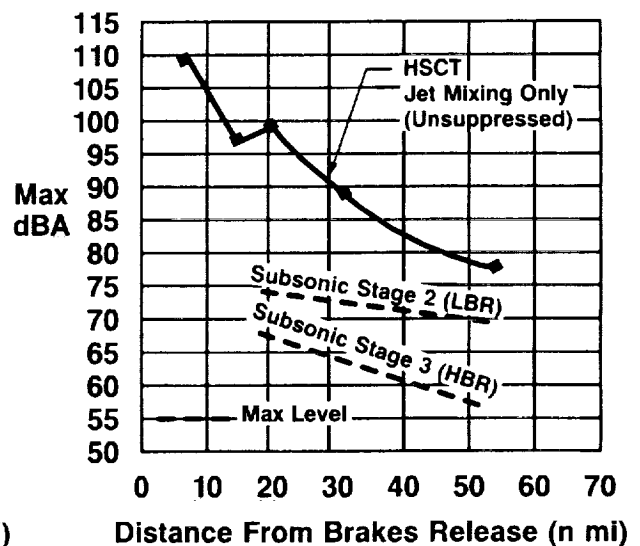
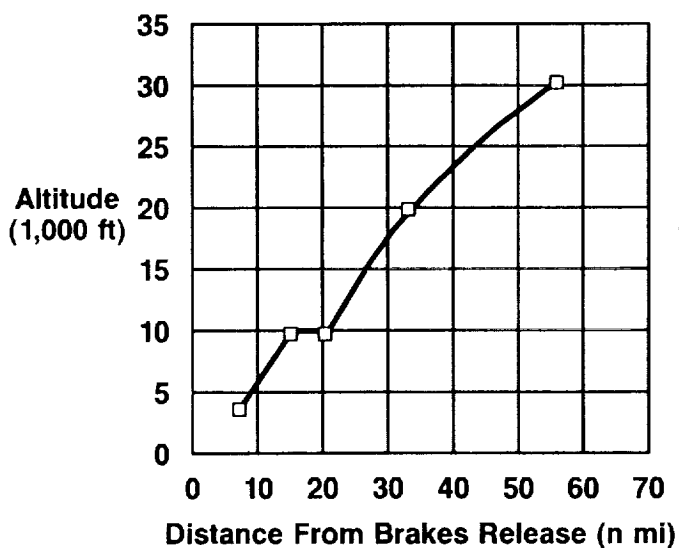


	HSCT 3.2-3A	747-400
Engines	GE VCE	PW 4256
Lift Devices	80% LE Suction	10-deg Flaps
Takeoff Velocity	230 Knots	185 Knots
Weights	800,000 lb	870,000 lb
Noise Levels		
Sideline	Stage 3	Stage 3-3.3
Takeoff	Stage 3-3	Stage 3-4.5

SIGNIFICANT NOISE SUPPRESSION MAY BE REQUIRED DURING CLIMB TO CRUISE PHASE

The attached graph plots altitude versus distance from brake release for a standard takeoff climb profile. Noise levels are then plotted for the stage 2 and stage 3 subsonic fleet, along with predicted climb-to-cruise noise levels for an HSCT. Note that only jet mixing noise in the unsuppressed mode is considered. (That is, no shock noise effects.) The plot indicates that HSCT climb-to-cruise noise could be significantly greater than the existing subsonic fleet, which at the time of HSCT certification and service entry will be limited to stage 3 subsonic aircraft. It should also be noted that the prediction codes for this regime have not been validated for HSCT engine/airframe concepts. These conditions suggest the climb-to-cruise noise should not be neglected in future noise assessments.

Significant Noise Suppression May Be Required During Climb-to-Cruise Phase

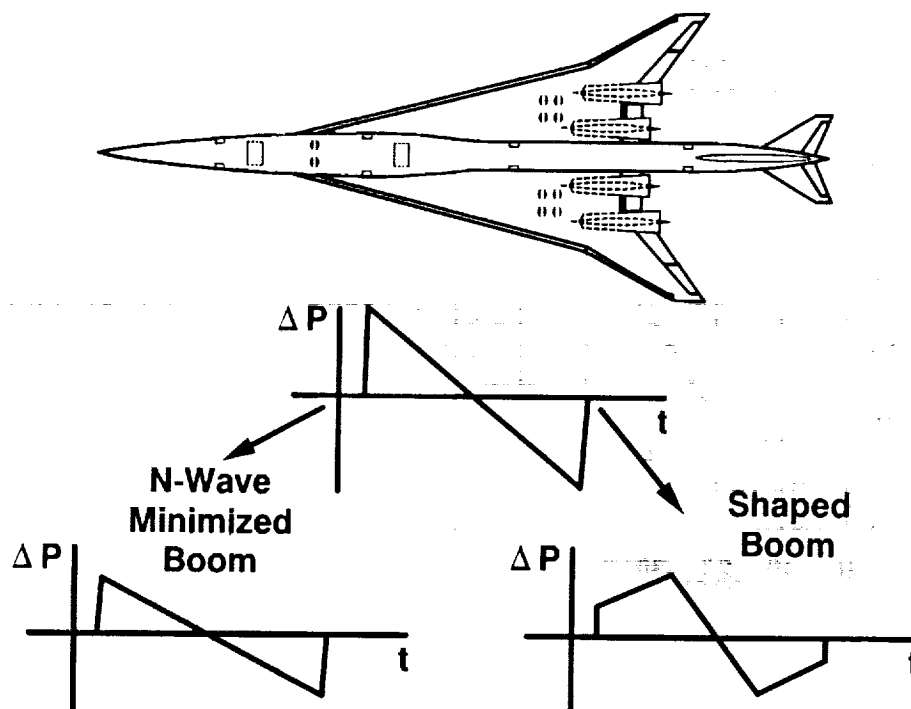


TWO APPROACHES TO SONIC BOOM MINIMIZATION

Douglas has continued to study advanced concepts for reducing the level of perceived noise resulting from the sonic boom produced by an HSCT flying supersonically. This technology could result in an aircraft which could be permitted to fly supersonically over land in either an unrestricted mode, or perhaps along some predetermined supersonic overland corridors. Any supersonic overland flight in the U.S. would require extensive research into public acceptance and changes to current regulations.

There are two general approaches to sonic boom minimization. The typical N-wave associated with a sonic boom may be modified to reduce the perceived noise level. Careful aerodynamic shaping of the aircraft and improved overall performance resulting in lower aircraft weight can help to reduce the maximum overpressure levels of the shock wave, resulting in a lower noise level sonic boom. Perceived noise level can also be reduced by increasing the rise time of the wave overpressure. This is referred to as a shaped boom, which is produced through careful shaping of the aircraft planform and distributions.

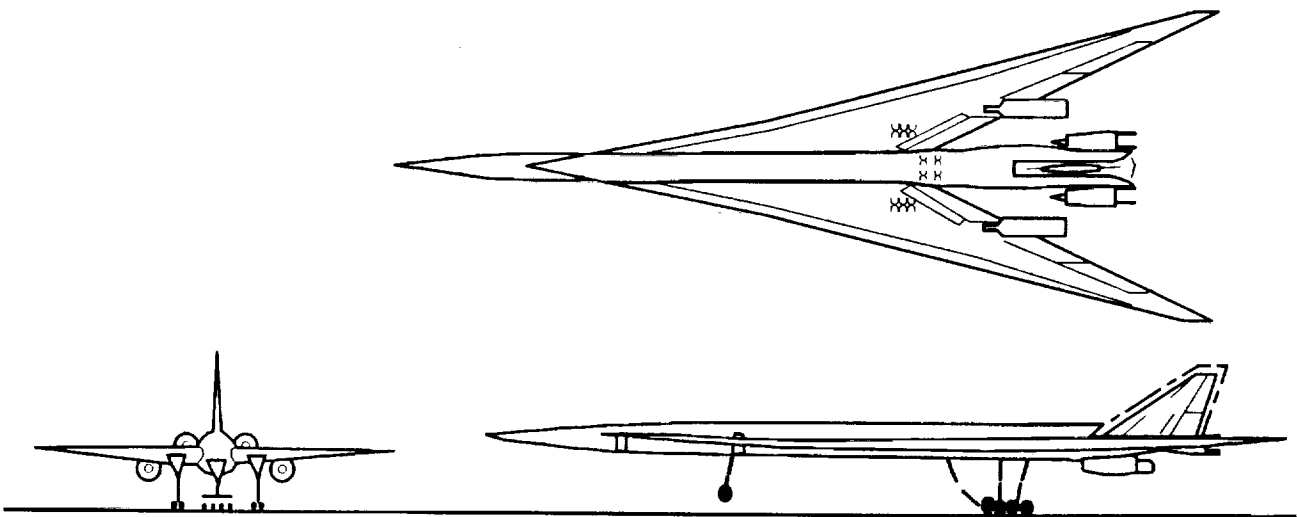
Two Approaches to Sonic Boom Minimization



INITIAL LOW SONIC BOOM DESIGNS MEET LOUDNESS GOALS WITH REDUCED PERFORMANCE

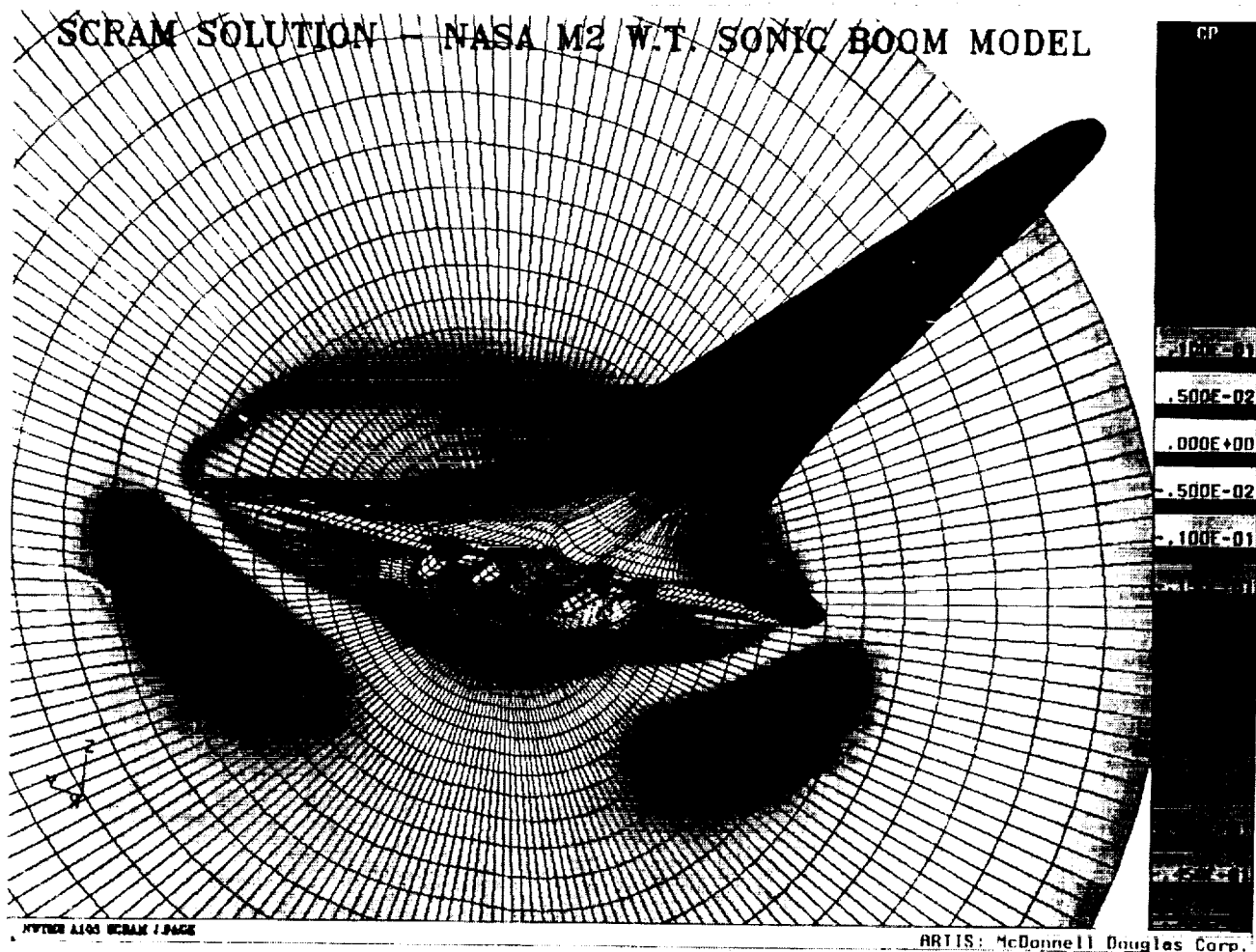
Douglas has been developing low sonic boom concepts under our NASA Langley system studies contract over the last several years. A typical configuration resulting from these studies is shown here. The high sweep, high aspect ratio wings result from the combination of cruise requirements at Mach 3.2, and careful shaping and area distribution to shape the sonic boom waveform. This configuration met our sonic boom goals of 0.6 psf and 90 PLdb, but at a reduced range level which would not support economic viability. The design has some obvious operational issues associated with it, but the achievement of the low noise level was a significant step forward. A more in depth discussion of related work will be presented in the Douglas presentation and report in the sonic boom section of the workshop.

***I**nitia**l** Low Sonic Boom Designs Meet Loudness Goals With Reduced Performance*



SCRAM SOLUTION - NASA M2 W.T. SONIC BOOM MODEL

In addition to conducting sonic boom minimization studies, Douglas has been involved in the development and validation of advanced design and analysis methods for sonic boom prediction techniques. The attached chart shows the results of a CFD solution using the MDC SCRAM code to model the aerodynamics of the NASA M2 sonic boom wind tunnel model. We are working cooperatively with NASA to improve the fidelity of CFD codes to enhance design and analysis techniques.



HSCT KEY TECHNOLOGIES

In addition to the key environmental technologies, Douglas is working together with NASA to identify and initiate the development of key HSCT technologies. These include but are not limited to computational fluid dynamics (CFD), advanced materials and structures, producibility and manufacturing technology, advanced aircraft systems, propulsion efficiency and thrust/weight, and laminar flow control. The pages that follow discuss some of the key issues with respect to these technologies and some of the development efforts underway at MDC.

***K**^{HSCT}ey Technologies*

Environment

- Exhaust Emissions
- Source Noise Suppression
- Low Speed/High Lift
- Sonic Boom

Performance Economics

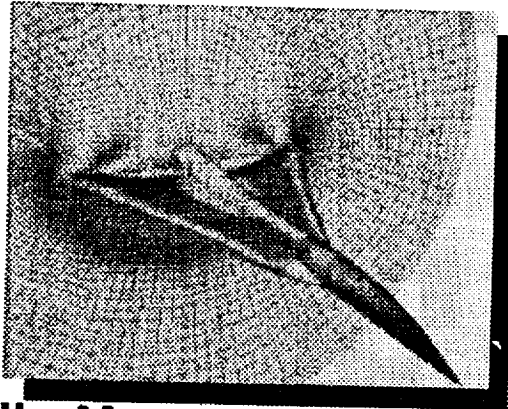
- Computational Fluid Dynamics
- Advanced Materials
- Producibility/Manufacturing Technology
- Propulsion Efficiency and Thrust/Weight
- Laminar Flow Control
- Advanced Aircraft Systems

CFD SOLUTIONS AT CRUISE AND LOW SPEED FOR TWO HSCT CONCEPTS

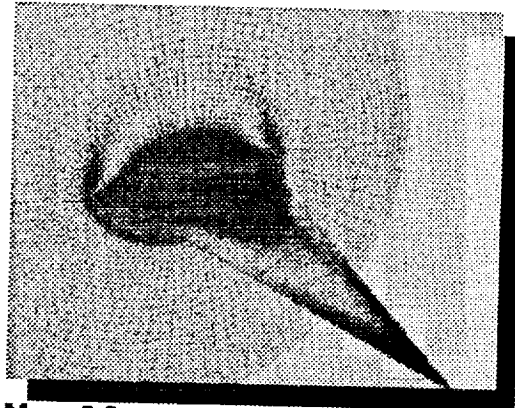
Douglas has made extensive use of CFD for HSCT studies for some time. The solutions shown are examples of CFD analyses conducted for our Mach 3.2 and Mach 5.0 concepts for both low speed ($M=0.3$) and cruise speed conditions. CFD development efforts throughout the components of McDonnell Douglas cooperation have contributed to the current CFD capabilities at Douglas. The further development and validation of CFD tools for HSCT design and analysis is warranted and will continue.

CFD Solutions at Cruise and Low Speed for Two HSCT Concepts

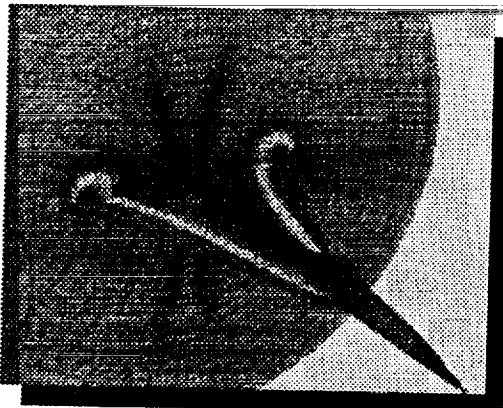
$M = 3.2$



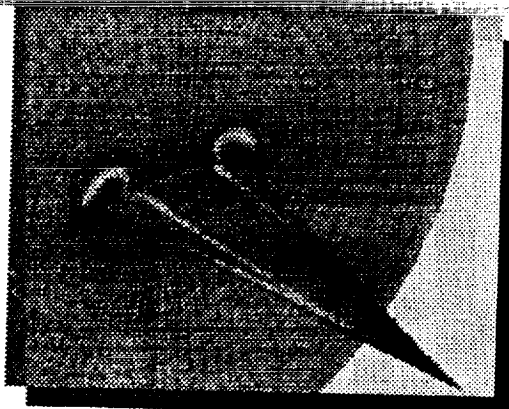
$M = 5.0$



$M = 0.3$



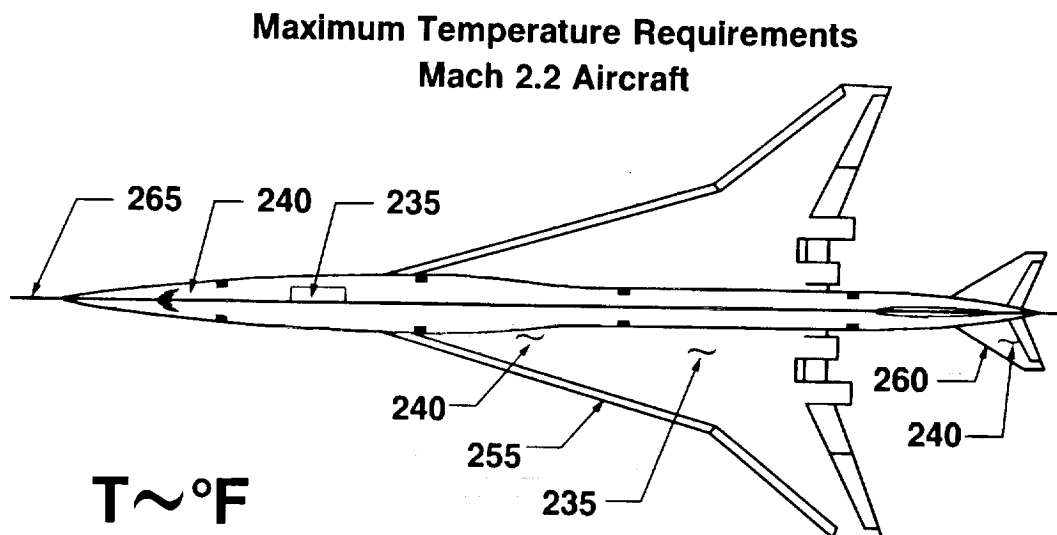
$M = 0.3$



AIRFRAME THERMAL AND STRUCTURAL ANALYSIS MUST BE HIGHLY INTEGRATED

Materials and structures technology is a critical aspect of the HSCT program. In order to select candidate materials for further development toward application to an HSCT, detailed airframe design and analyses must be conducted. This chart illustrates typical skin temperatures for a Mach 2.2 HSCT at cruise. Structural design and analyses must be highly integrated with thermal analyses in order to accurately predict structural response and make proper material selections for aircraft structure. The effects of transient thermal conditions, through-the thickness thermal gradients, etc., all must be properly taken into account.

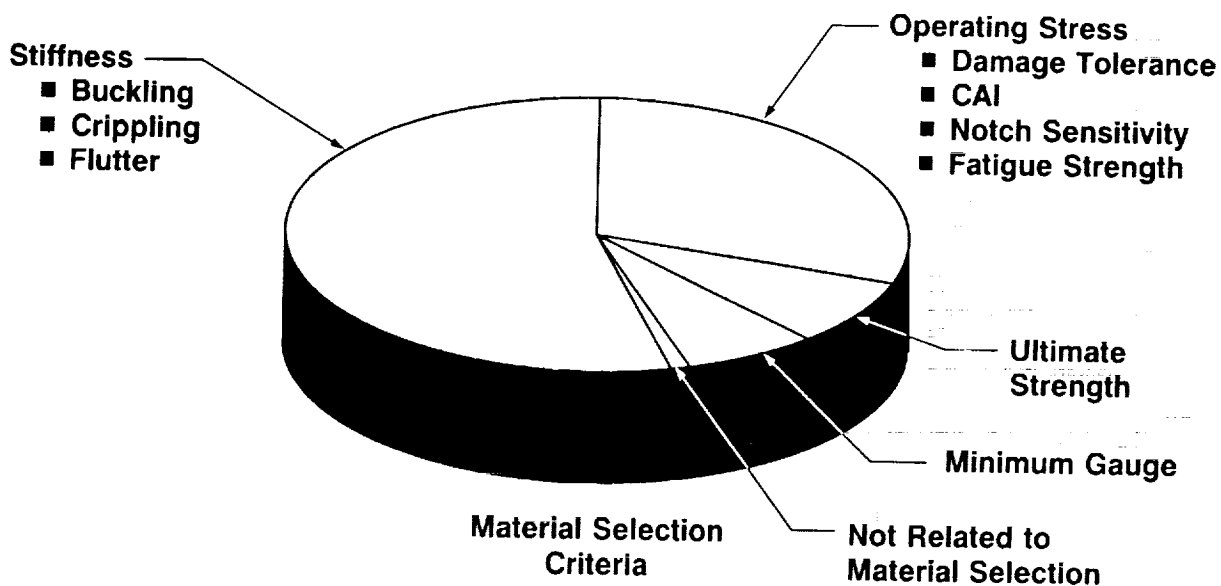
Airframe Thermal and Structural Analysis Must Be Highly Integrated



STRUCTURAL WEIGHT DRIVERS FOR AN HSCT AIRCRAFT

The attached chart shows a typical distribution of critical design criteria for the structure of an HSCT. An understanding of this distribution is used to make material selections for the various parts of the airframe. This particular chart was developed for an HSCT airframe based on fiber reinforced materials application. Note that the majority of the structure is designed by stiffness criteria such as buckling, crippling, and flutter requirements. A relatively small percentage of the structure is designed by minimum gage. These serve as a guide for the design process, with the final material selections based upon more detailed design and analysis.

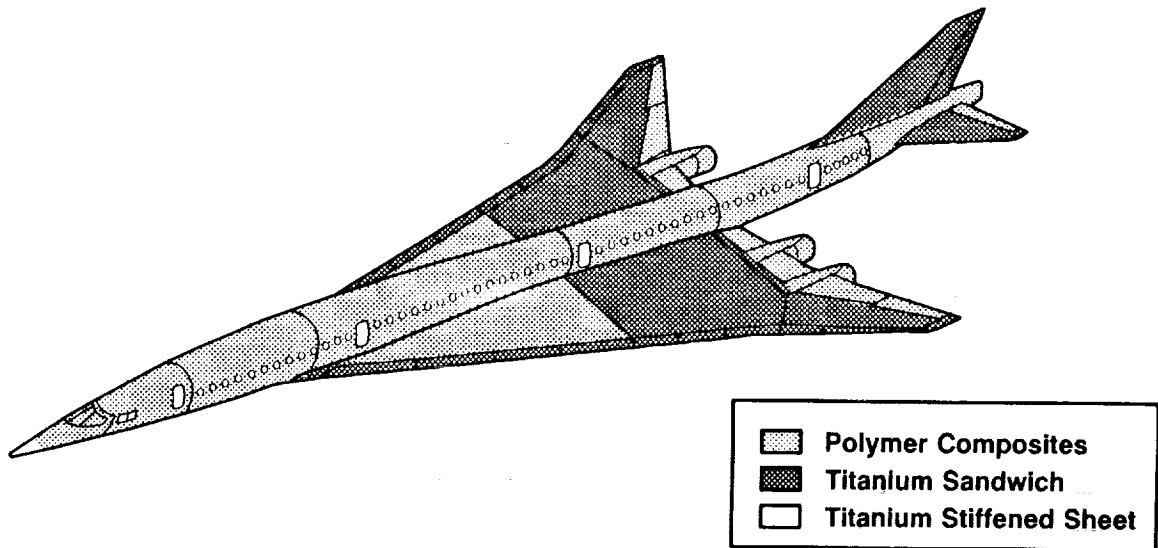
Structural Weight Drivers for an HSCT Aircraft



MDC 1991 M 2.4 MATERIAL STUDY DESIGN FEATURES MULTITPLE MATERIALS

In many cases, the most efficient airframe structure consists of a combination of materials. In the example shown below, the preferred concept was a combination of fiber reinforced polymer composite materials and titanium materials in both sandwich and stiffened sheet construction. Material selections are made with performance, durability, productibility, and cost considerations in mind. The Douglas presentation and report in the structures and materials section of the HSR workshop presents more detail on the subject of material selection.

***M**ultiple Materials Featured in MDC 1991 M2.4 Material Study Design*



HSR PROPULSION SYSTEM STUDIES

The development of an efficient, low noise, low emissions propulsion system for the HSCT is critical to the success of the program. Douglas is working closely with engine manufacturers to design and evaluate the best engine/airframe combination. Four of the promising engine concepts being developed by the Pratt & Whitney/General Electric team in conjunction with NASA Lewis Research Center are shown below.

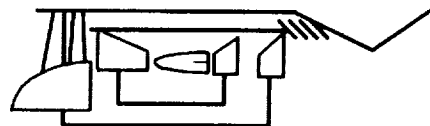
HSR Propulsion System Studies *Candidate Propulsion Concepts*

Turbine-Bypass Engine



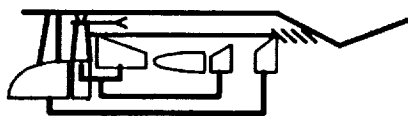
- Simple Cycle
- Low Cruise Temperature

Mixed-Flow Turbofan



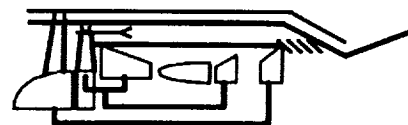
- Low Jet Velocity
- Good Subsonic SFC

Variable-Cycle Engine



- Variable Bypass
- Good Subsonic SFC

Flade Engine

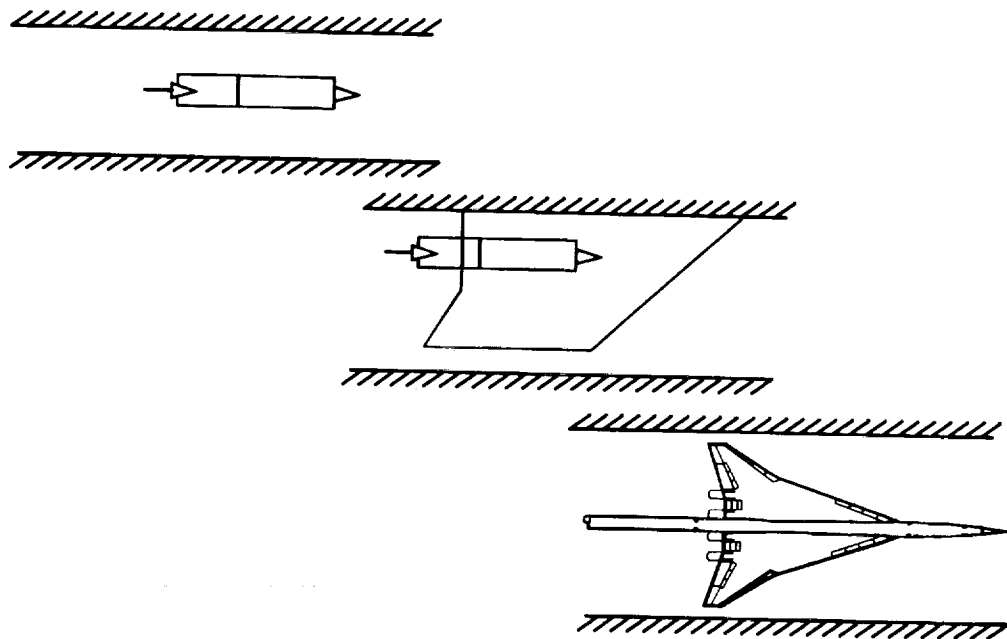


- Low Jet Noise
- Variable Bypass
- Good Subsonic SFC

DAC CONTRACT WITH NASA-LEWIS WILL ADDRESS
PROPULSION/AIRFRAME INTEGRATION ISSUES

Douglas is currently under contract to NASA Lewis Research Center to conduct engine/airframe integration studies for HSCT concepts. Current plans contain an incremental wind tunnel test program for inlet concept development. Testing will begin with single inlet/nacelle testing to full planform tests with engine nacelles integrated on the aircraft.

***D**ouglas Contract With NASA-Lewis Will Address Propulsion/Airframe Integration Issues*



SUPERSONIC LAMINAR FLOW CONTROL

Laminar Flow Control (LFC) is key technology for HSCT in terms of the potentially tremendous benefits resulting from increased supersonic cruise performance. Should we fall short of our goals in other key technologies, LFC may be critical to ensuring program economic viability. Douglas studies indicate that reductions in cruise drag through the integration of an LFC system on an HSCT will result in block fuel reductions of 10 to 20 percent, depending on the aircraft cruise mach number and range. Associated benefits also include smaller engines, improved L/D, reduced TOGW, and overall improvements in operating economics. Technology development efforts required to realize these benefits have been identified, some of which are shown below.

***S**upersonic Laminar Flow Control (SLFC)*

Benefits for HSCT

- 8% TOGW Reduction
- 12% Smaller Engines
- 14% Block Fuel Reduction
- 11% L/D Improvement
- 4% Better Economics

Technology Issues

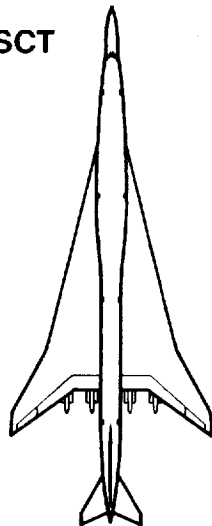
- CFD for High-Speed Analysis and Design
- 3-D Boundary Layer Stability Analysis Package
- Perforated Advanced Materials Development
- Development of SLFC Structures and Ducting Using Advanced Materials
- Development and Integration of Large Suction Motors

PRELIMINARY DESIGN STUDIES UNDER NASA LANGLEY CONTRACT ARE FOCUSED
ON A SUPERSONIC LAMINAR FLOW CONTROL FLIGHT TEST EXPERIMENT

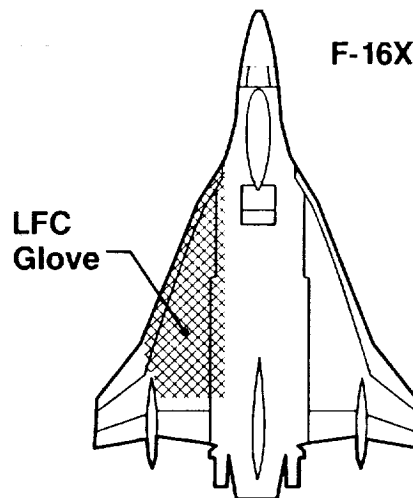
Douglas is currently under contract to NASA Langley to examine the design issues associated with an SLFC flight test experiment using an F-16XL aircraft. This aircraft is considered an appropriate test bed because of the similarity in wing planform of the F-16XL to candidate HSCT designs. We are currently working with NASA to identify the type of development and test activities that would most effectively contribute to the successful application of this technology to an HSCT. The Douglas presentation and report in the LFC session of this workshop will discuss this activity in more detail.

Preliminary Design Studies Under
NASA-Langley Contract Are Focused
on a Supersonic Laminar Flow Control
Flight Test Experiment

Douglas HSCT



F-16XL-2



HSCT-RELATED AIRCRAFT SYSTEM ISSUES

The development of critical aircraft systems for the HSCT is a key to program success. Many advanced systems currently being developed for advanced subsonic transports (such as fly-by-light systems, electro/mechanical actuators, etc.) will also be applicable to the HSCT. But there are also system requirements which are unique to the HSCT, some of which are identified below. NASA Phase 2 HSR plans include a significant investment in technology development to address these issues, as appropriate.

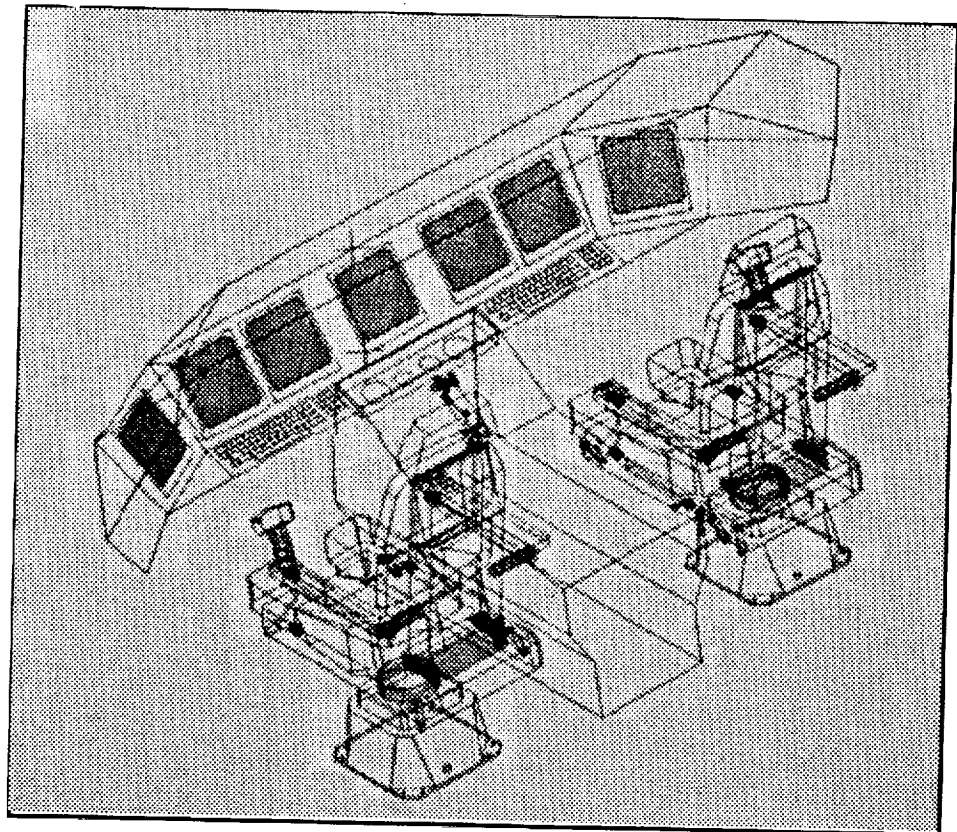
Aircraft System Issues Related to HSCT

<u>System</u>	<u>Issue</u>
Crew Systems (Flight Deck)	Restricted Visibility Space-Constrained Cockpit ATC Compatibility
Propulsion Subsystems	Integrated Control of Inlet/Engine/ Nozzle/Airframe (Integrated Flight/ Propulsion Control) CG Management
Flight Control	Integrated Flight/Propulsion Control Aircraft Stabilization Flexible Mode Control Takeoff/Landing Performance System Architecture

CREW SYSTEMS TECHNOLOGY

Douglas is active in the development of advanced crew systems technology for both subsonic and supersonic transport concepts. The drawing below is representative of an advanced flight deck concept for a future HSCT. These studies will continue over the next several years as the design mach number and associated technologies are selected.

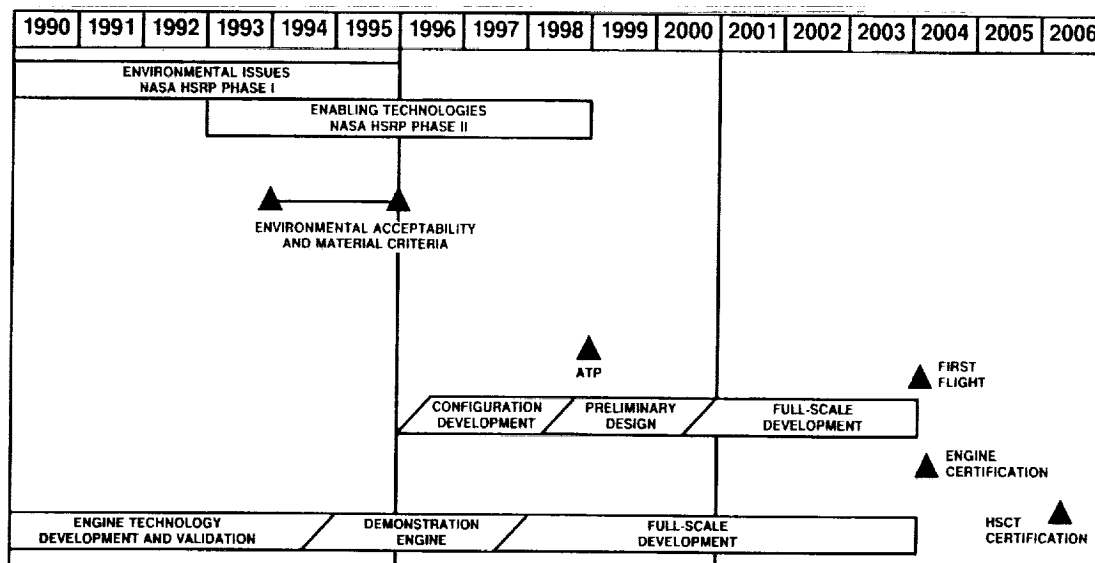
Crew Systems Technology



CURRENT STUDIES ARE BASED ON AIRCRAFT CERTIFICATION IN YEAR 2006

Douglas is currently following a parallel path approach to HSCT development. As shown earlier, we are currently evaluating multiple designs at different cruise mach numbers, and will continue this approach until program risk has been reduced to an acceptable level such that a single configuration may be selected. The critical step in achieving this condition is the timely development of environmental criteria which are accepted and adopted on a world-wide basis. Douglas is taking an active role in trying to advance this process. Despite these uncertainties, we advocate the development of long lead technologies required to meet our program milestones, particularly those which are not heavily dependent on cruise mach number. We believe that the NASA HSR program is consistent with our plans, pending the selection of a cruise mach number.

Current Studies Are Based on: Aircraft Certification in Year 2006



SUMMARY

McDonnell Douglas is committed to the successful development and production of a High Speed Civil Transport for service entry beyond the turn of the century. We will maintain a parallel path approach to our configuration design studies until programs risks associated with uncertainties in environmental design criteria and technology development issues are reduced. An aggressive technology development program as outlined in NASA's long range plan for high speed research is critical to overall program success.

***S**ummary*

Near-Term Studies Focus on Environmental Issues and Economic Viability

- Technology Requirements
- Operational Criteria

MDC Study Effort Will Continue in Mach 1.6-2.4 Range

Aggressive Technology Development Effort Required

- NASA/Industry Initiative
- Near-Term Attention to Long-Lead Issues

Economic Viability Is Achievable Within Current Assumptions Given Timely Technology Development and Environmental Criteria

- Atmospheric Effects

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Session I. Plenary Session

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General Electric/Pratt & Whitney Summary Report

Samuel C. Gilkey, GE Aircraft Engines; and Richard W. Hines, Pratt & Whitney Aircraft

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General Electric/Pratt & Whitney Summary Report

First Annual High Speed Research Workshop
May 14, 1991
Williamsburg, Virginia

Samuel C. Gilkey
GE Aircraft Engines

Richard W. Hines
Pratt & Whitney Aircraft

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GE and P&W Agreement

On October 9, 1990, GE Aircraft Engines (GEAE) and Pratt & Whitney (P&W) announced their agreement to cooperate on the development and production of the propulsion system for the next generation of supersonic commercial aircraft, a Mach 1.5 to 3.5 High Speed Civil Transport (HSCT). In teaming, we are combining the best talents of the U.S. propulsion industry to meet the technical challenge of developing an environmentally acceptable and economically viable second generation supersonic transport.

Although the HSCT propulsion system is a logical next step in commercial aircraft engine technology beyond those currently existing or contemplated, its development will undoubtedly require resources significantly greater than are available at any one existing United States engine company. Neither P&W or GEAE could realistically consider developing such a system alone. The HSCT propulsion system technology and development costs will be several times greater than subsonic transport propulsion costs. Considering the limited application of this propulsion system and the long time to recover investments, the HSCT propulsion system becomes a very high-risk project for any individual company to undertake.

Significant research and development is needed over the next decade to establish the framework for the introduction of the HSCT. GE Aircraft Engines and Pratt & Whitney working with NASA plan to lead the world in developing this propulsion system technology.

GE and P&W Agreement

- Restricted to HSCT propulsion system M1.5-3.5
- Two phases
 - Study phase
 - Evaluate technical and market feasibility
 - Technology development
 - Implementation phase
 - Technology development and validation
 - System development
 - Engine certification and production
- Strategy board - study phase
- Program manager - implementation phase

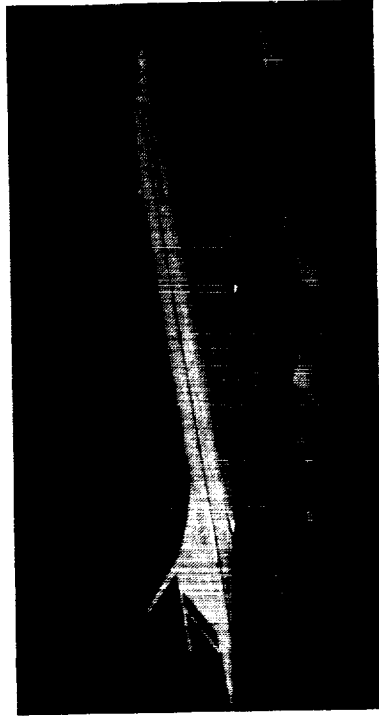
The Technical Challenge

With passengers well aware of the physical and time demands of long subsonic flights, a second generation supersonic transport can have a significant impact on the long range international travel market, provided it is both environmentally acceptable and economically competitive. This is particularly true in the Pacific basin where, for example, the flight time from Sydney to Los Angeles can be reduced to 6 hours from 13 hours.

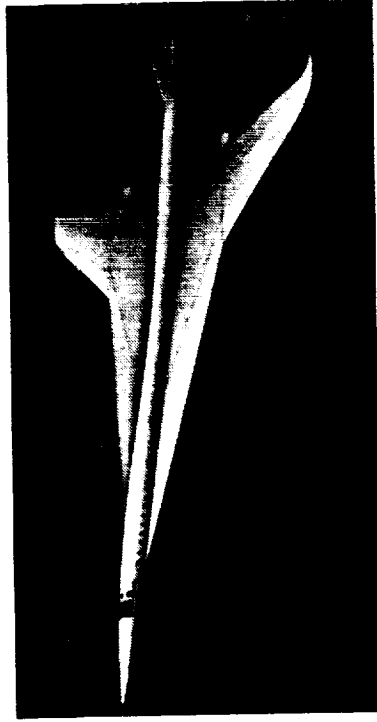
A comparison of the second generation supersonic transport with the first generation SST, the Concorde, highlights major differences between the aircraft, the most significant being the need to improve the operating economics eight times. It should be noted that the Concorde is a significant technical achievement. Concorde has proven that a supersonic airplane can be operated safely and effectively by the airlines. The aircraft cruise Mach number is not significantly different; the second generation SST or HSCT (High Speed Civil Transport) will cruise at Mach 2.0 to 2.5 depending upon the aircraft structural materials and possibly the environmental impact of the engine emissions.

Major differences are in the payload and range of the aircraft and its environmental acceptability. The HSCT's payload is increased from the 105 first class passengers on Concorde to about 300 passengers in three classes (first, business, and coach). Range of the airplane is increased from 3000 nautical miles to 5000 to 6000 nautical miles. Because there are only 14 Concorde in service with the airlines, they operate under special exceptions to the noise regulations, and engine emissions do not represent a major atmospheric concern. Assuming a fleet of 500 HSCT's is needed in the period of 2005 to 2025, it is clear that their impact on the environment must be carefully considered in the design process. The increase in payload and range is not, however, enough to satisfy our goal of an eightfold gain in the operational economics of the airplane. Technology improvements in both the aircraft and, more importantly, in the propulsion system are needed to deliver a competitive and environmentally acceptable aircraft to the market in 2005.

The Technical Challenge



Concorde



HSCT

Second Generation Supersonic Transport Versus Concorde			
Range		2 times greater	
Payload		3 times greater	
Economics		8 times greater	

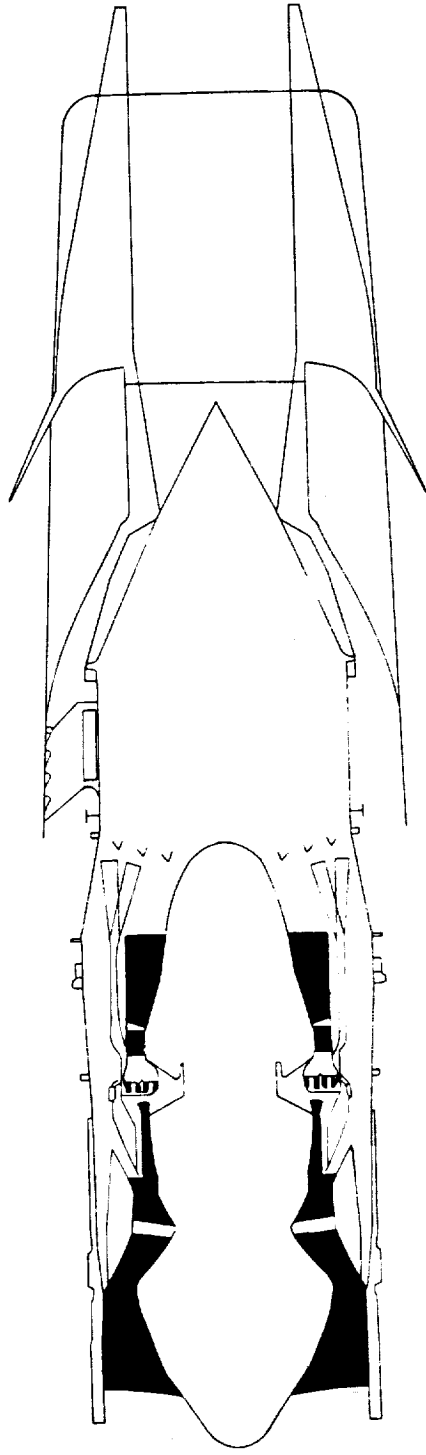
Environmental Challenges

Current research is now focused on addressing the major environmental issues of airport noise, engine emissions, and sonic boom. GEAE and P&W are studying a variety of engine and exhaust nozzle concepts and validating the emissions and acoustics technologies needed for this aircraft.

Two of the three major environmental concerns relative to the HSCT, emissions and airport noise, are directly attributable to the propulsion system. The third, sonic boom, may require the engine to be efficient at subsonic as well as supersonic cruise conditions.

The HSCT mission demands the propulsion system have excellent supersonic cruise performance, good subsonic cruise performance to satisfy the overland sonic boom constraints, and low emissions at cruise for minimal impact on the ozone layer. In addition, the engine must meet the airport noise rules with minimum system weight and performance penalties and deliver years of safe, reliable service with extended engine operation near full power.

Environmental Challenges



- Emissions (compatibility essential)
- Airport noise (compliance essential)
- Sonic boom (alleviation if possible)

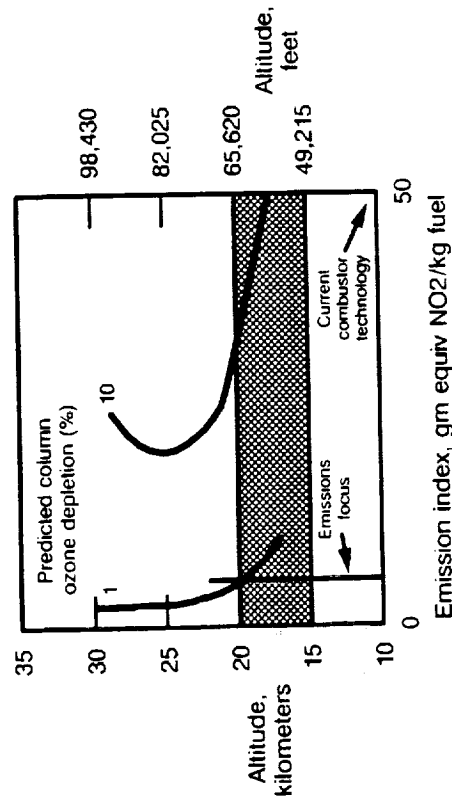
Engine Emissions Assessment

Emissions are a global issue and key to proceeding with the HSCT. Compatibility with the atmosphere is essential; however, the levels of engine emissions required for atmospheric compatibility are not understood at this time. The magnitude of the impact of engine emissions is uncertain and highly dependent on the altitude and latitude at which the engine emissions are occurring, the amount and chemical composition of emissions from a particular engine design, and the aircraft fleet size and operation. In assessing possible atmospheric changes, the modeler also needs to account for changes in the future atmosphere. The assessment of the impact of a HSCT fleet is a major global atmospheric modeling challenge for the scientific community. NASA is addressing this in the Atmospheric Effects of Stratospheric Aircraft (AESA) studies that began in 1990.

The current HSCT designs cruise for best performance between 15 and 20 kilometers depending upon cruise Mach number. It should be stressed that at this altitude there is great uncertainty in the atmospheric models because of the lack of understanding of the transport mechanisms between the troposphere and the stratosphere and the models' resolution. Current models need to be improved to address this critical region.

Results from one-dimensional atmospheric models for 500 HSCT's illustrate the importance of cruise altitude and engine emissions. Calculating the amount of NO_x discharged into the atmosphere is a product of the emission index of the combustor, the efficiency of the engine (specific fuel consumption), the airplane mission, and the fleet size. Current combustors have an emission index of around 50 grams equivalent of NO_x per kilogram of fuel burned. The goal of the NASA HSR Program is to validate combustor technology with an emission index of 5 grams per kilogram of fuel. P&W and GEAE are evaluating combustor designs that operate either rich or lean to meet the NASA HSR Program goal.

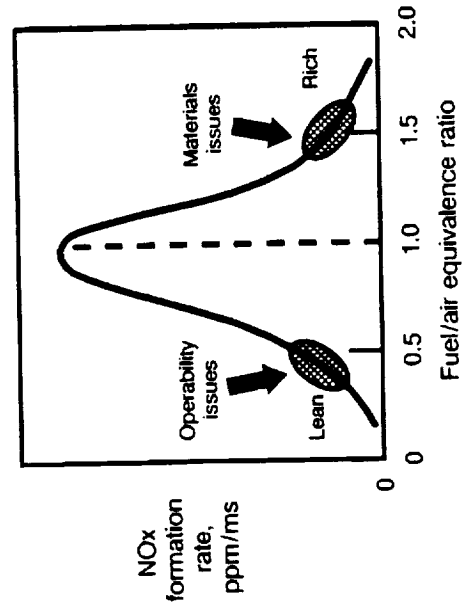
Engine Emissions Assessment



- Column ozone impact depends on total NO_x generated

- Number of aircraft
- Number of flights
- Cruise altitude and latitude
- Fuel burn
- Combustor emission index

- Current combustors NO_x emissions need to be reduced by an order of magnitude
- Advanced combustor concepts operating rich or lean are required
- NASA flame tube testing is encouraging



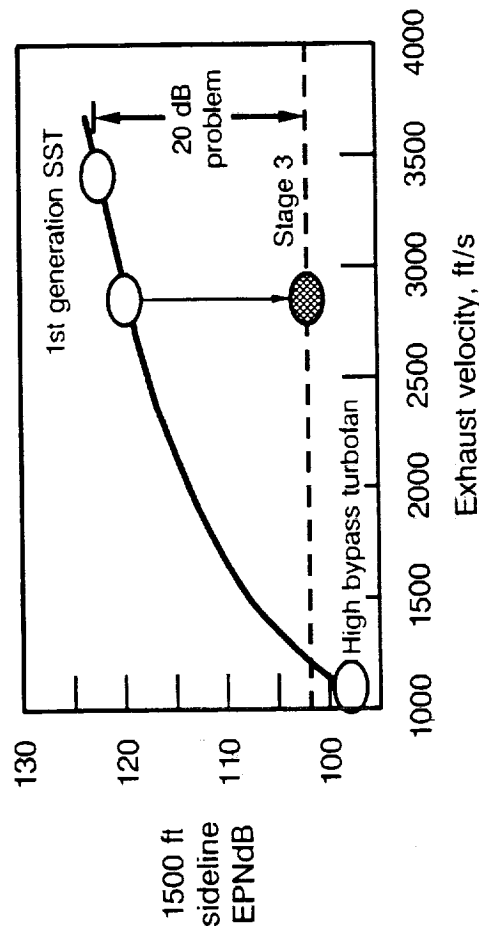
Airport Noise Assessment

It is expected that the HSCT will be required to meet the current subsonic aircraft noise regulations of FAR 36 Stage III. The difference between Concorde operation and Stage III is approximately 15 dB, or in other words, the HSCT must be 3 times quieter than Concorde. Compliance with the airport noise regulations is essential and has a major impact on the economics of the airplane. There is no fundamental scientific limitation on meeting the noise rule. Nevertheless, it is a challenging engineering job to develop the right combination of inlet, engine, and exhaust nozzle in an integrated propulsion system to meet the regulation with minimum impact on airplane TOGW.

The acoustic exhaust system may in all likelihood weigh as much as the engine and will have a major influence on the engine cycle selection. High specific thrust engines are the smallest and lightest weight for supersonic cruise. However, the high specific thrust engines make the most noise because of their accompanying high jet velocities.

In designing the exhaust system, emphasis must be placed on not only the acoustic performance but also the aerodynamic performance at both takeoff and supersonic cruise. In addition, careful consideration of the mechanical feasibility and system weight is needed. There has been significant progress in exhaust nozzle technology over the past 30 years. The pounds of exhaust system per dB of noise reduction has improved considerably since the GE4 engine. In the process, the complexity of the system has increased as evidenced by the number of actuation systems involved.

Airport Noise Assessment



- High specific thrust engines needed for good supersonic cruise performance
- What is the net impact on airplane TOGW and economics?

- Materials, aerodynamics, and acoustic technology have improved significantly since the GE4

Technology level	Nozzle Weight	Actuation systems	Suppression	lb/dB
GE4 (1960s)	4,825	3	4 dB	1,250
AST (1970s)	6,215	6	12 dB	517
HSCT (1990s)	5,065	6	17 dB	298

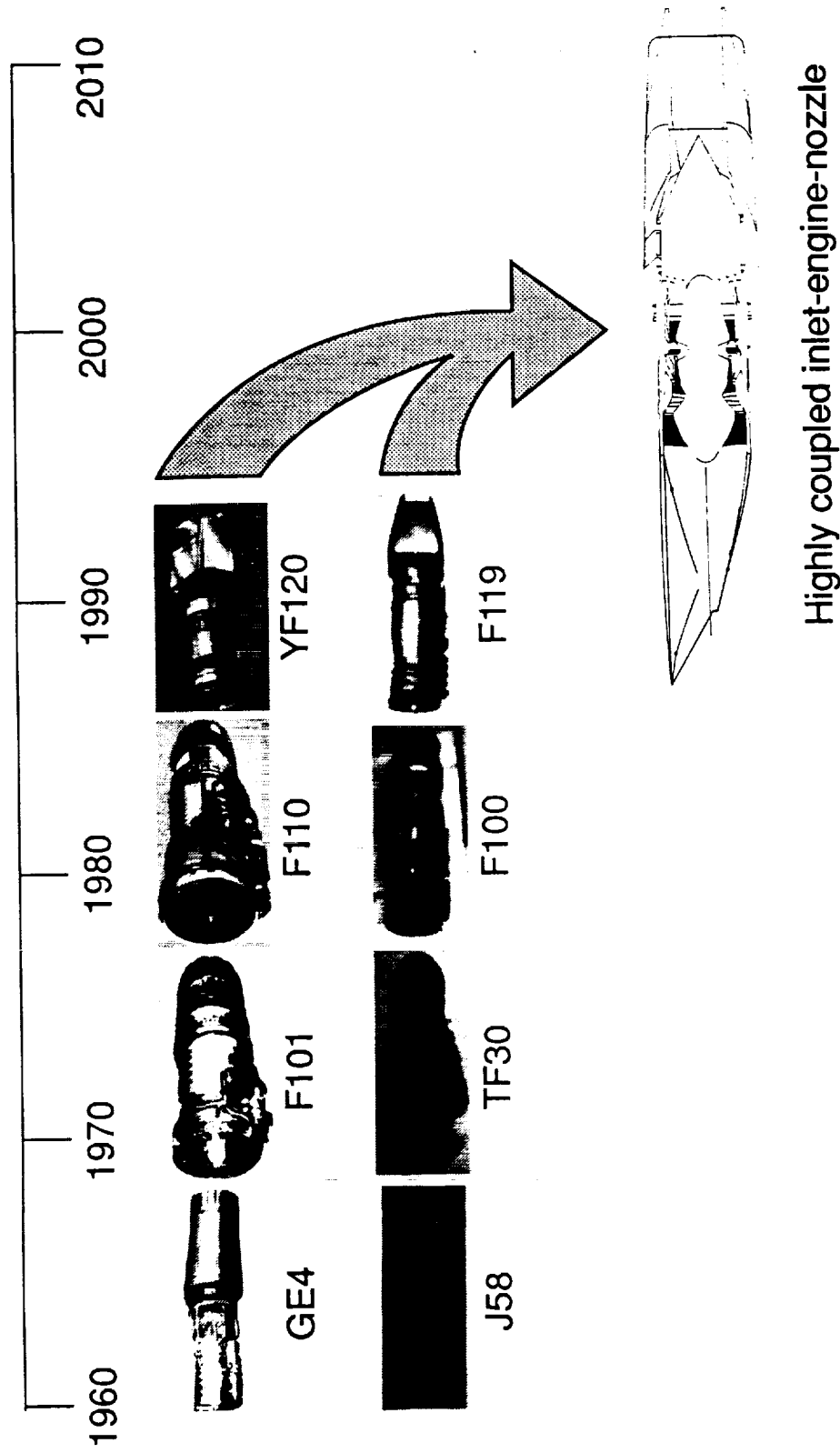
Evolution of Supersonic Engines

GEAE and P&W have a long heritage in propulsion system technology for supersonic flight. GE designed, built, and tested the GE4 turbojet engine for the USA SST program. P&W built the J58 used in the SR-71. Both companies continued to conduct research on supersonic propulsion system technology throughout the 1970's and early 80's. A significant data base relative to variable cycle engine technology including jet noise reductions was established under the NASA sponsored Supersonic Cruise Research and Variable Cycle Engine Technology programs.

In addition, P&W and GEAE continued to design and build supersonic military fighter engines such as the F100 and F110 leading to the development of the F119 and YF120 engines.

The next step in the evolution of supersonic engines is represented by the HSCT. The HSCT mission performance requires a highly integrated, closely coupled inlet-engine-exhaust nozzle design. This means closer working relationships between the aircraft and engine manufacturers.

Evolution of Supersonic Engines



Supersonic Engine Trends

The trends are anchored by the GE4 (EIS date 1972), and extend through AST studies of late 1970's to latest HSCT predictions. Military turbofan experience of 1970's and 1980's are included in thrust/weight and overall efficiency trends.

Gas Generator Ideal Thrust-to-Weight (sea level static conditions)

- Steady upward trend due to improved materials and design

Exhaust Nozzle Effectiveness

- Nozzle Weight/Noise reduction (EPNdB)
- Dramatic reduction (75%) from GE4 nozzle weight

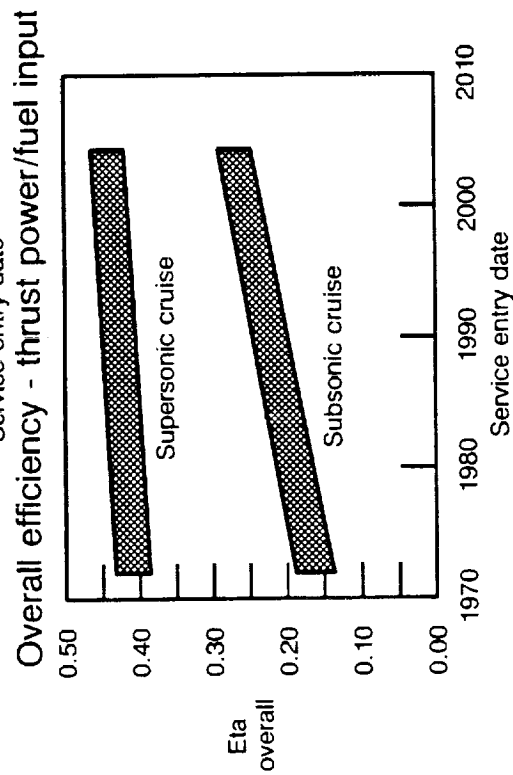
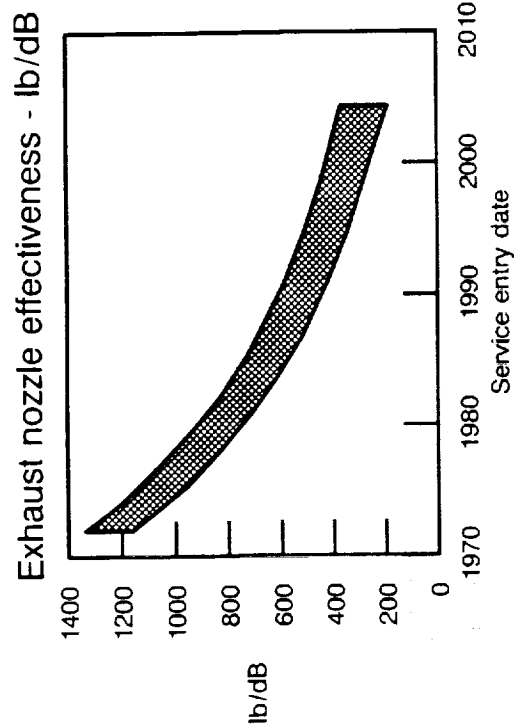
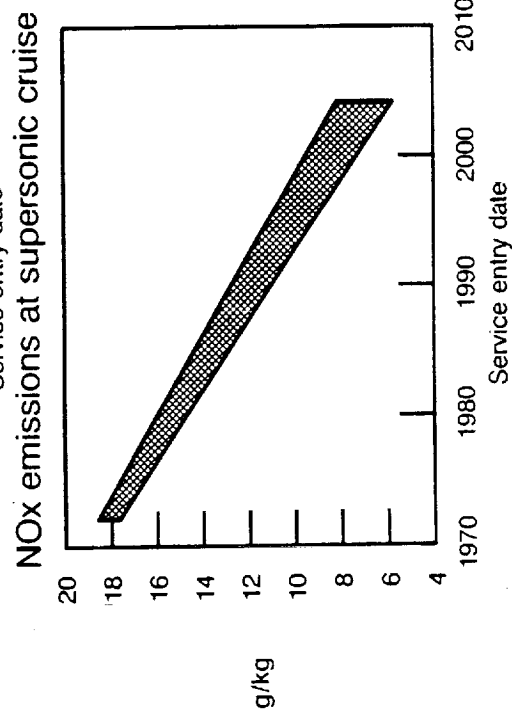
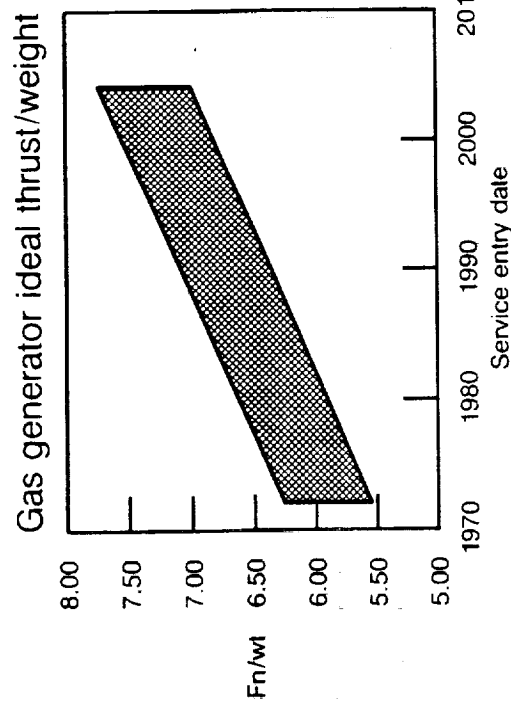
Supersonic Cruise Emissions

- Steady reduction to projected HSCT combustor designs

Overall Efficiency

- Shown for subsonic and supersonic cruise conditions
 - Modest improvements at supersonic conditions resulting from advances in design technology; earlier designs were near-optimum cycle
 - Improvements at subsonic conditions more pronounced due to use of cycles which give better propulsive efficiency subsonically, while preserving supersonic match.
-

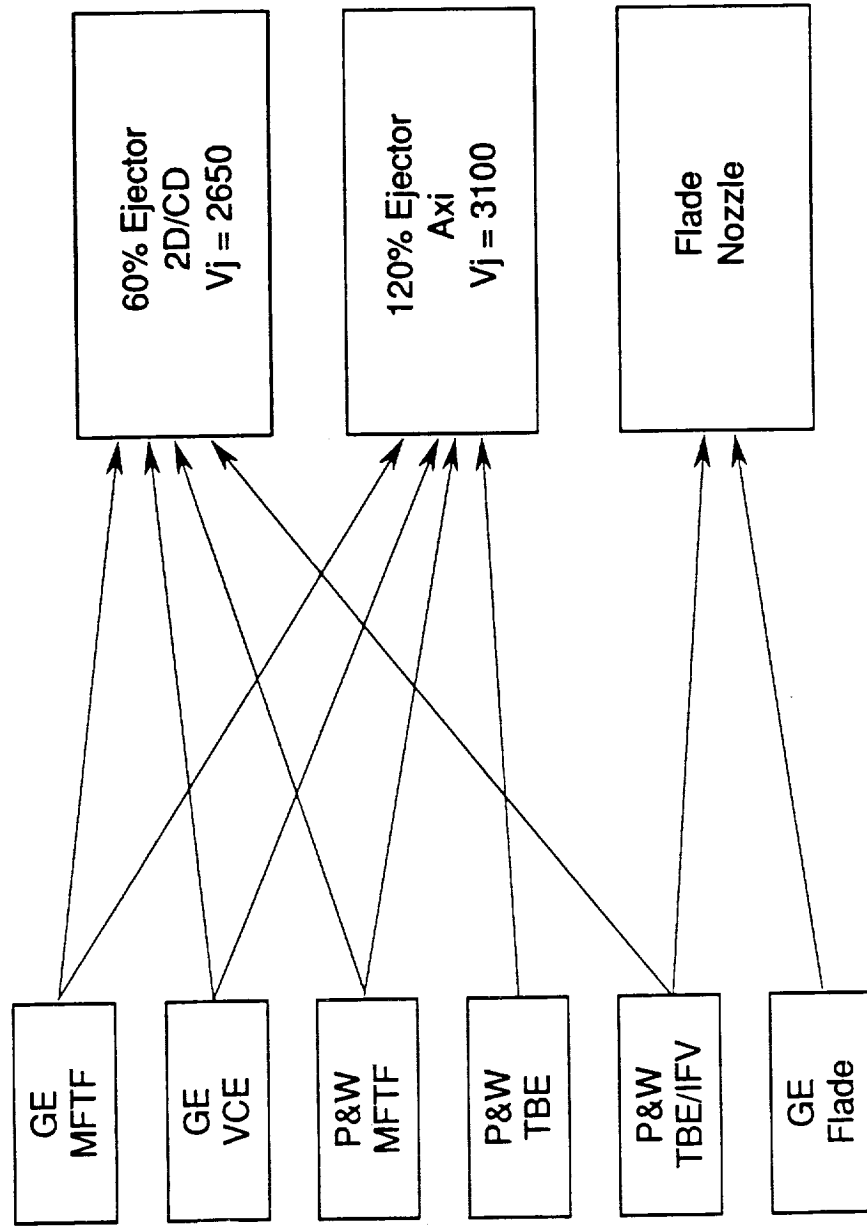
Supersonic Engine Trends



HST Engine and Nozzle Options - Being Evaluated

P&W and GEAE are evaluating a number of engine concepts, the mixed flow turbofan (MFTF), the variable cycle engine (VCE) (double bypass engine), the turbine bypass engine (TBE), the turbine bypass engine with inverted flow valve (TBE/IFV), and the fan on blade (FLADE). Three different exhaust nozzle concepts, one with 60% ejector flow, one with 120% ejector flow, and a fluid shield type nozzle for the FLADE, are being evaluated. Engine cycle studies are being conducted at Mach 2.4 and Mach 2.0 with both NASA and company funding.

HSCT Engine and Nozzle Options – Being Evaluated

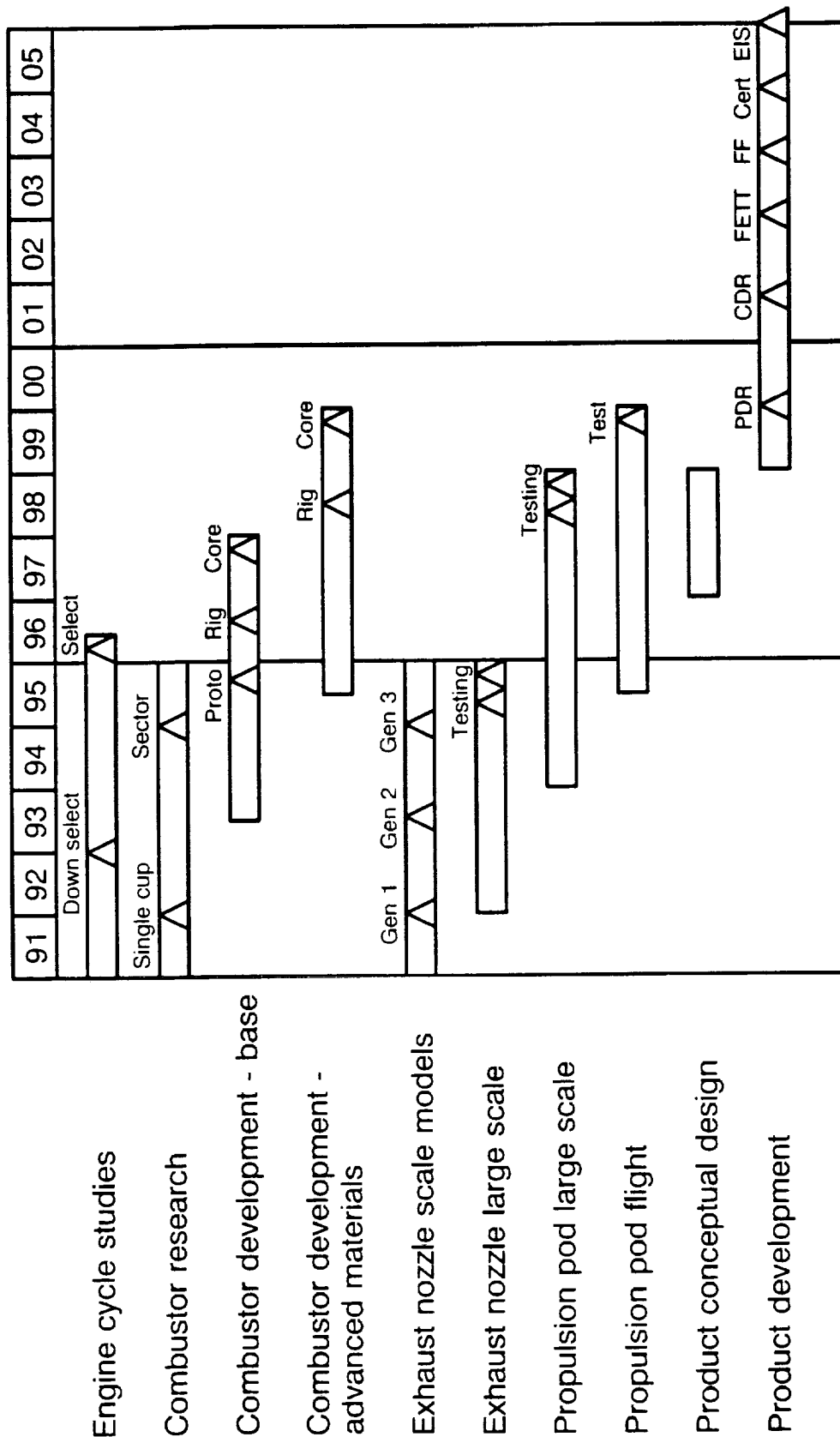


HSCT Propulsion Development Schedule

The HSCT Propulsion Development Schedule has been laid out to support an entry into service (EIS) of 2005. This is an aggressive schedule requiring significant funding for technology development beginning in 1992. Several major tests are envisioned including a large scale engine/exhaust nozzle ground test in 1995 aimed at take-off and approach noise; a propulsion pod (inlet-engine-exhaust nozzle) ground test in 1998 aimed at supersonic performance, exhaust nozzle operability, and a second or third generation exhaust nozzle for take-off and approach noise; and a subsonic flight test of the propulsion pod aimed at in flight take-off and approach noise.

The decision to launch into a production engine program in 1998 or 1999 will be based on these key tests, the progress in developing the advanced propulsion materials under the NASA Enabling Propulsion Materials program, and the aircraft companies progress.

HSCT Propulsion Development Schedule



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1992 Goals

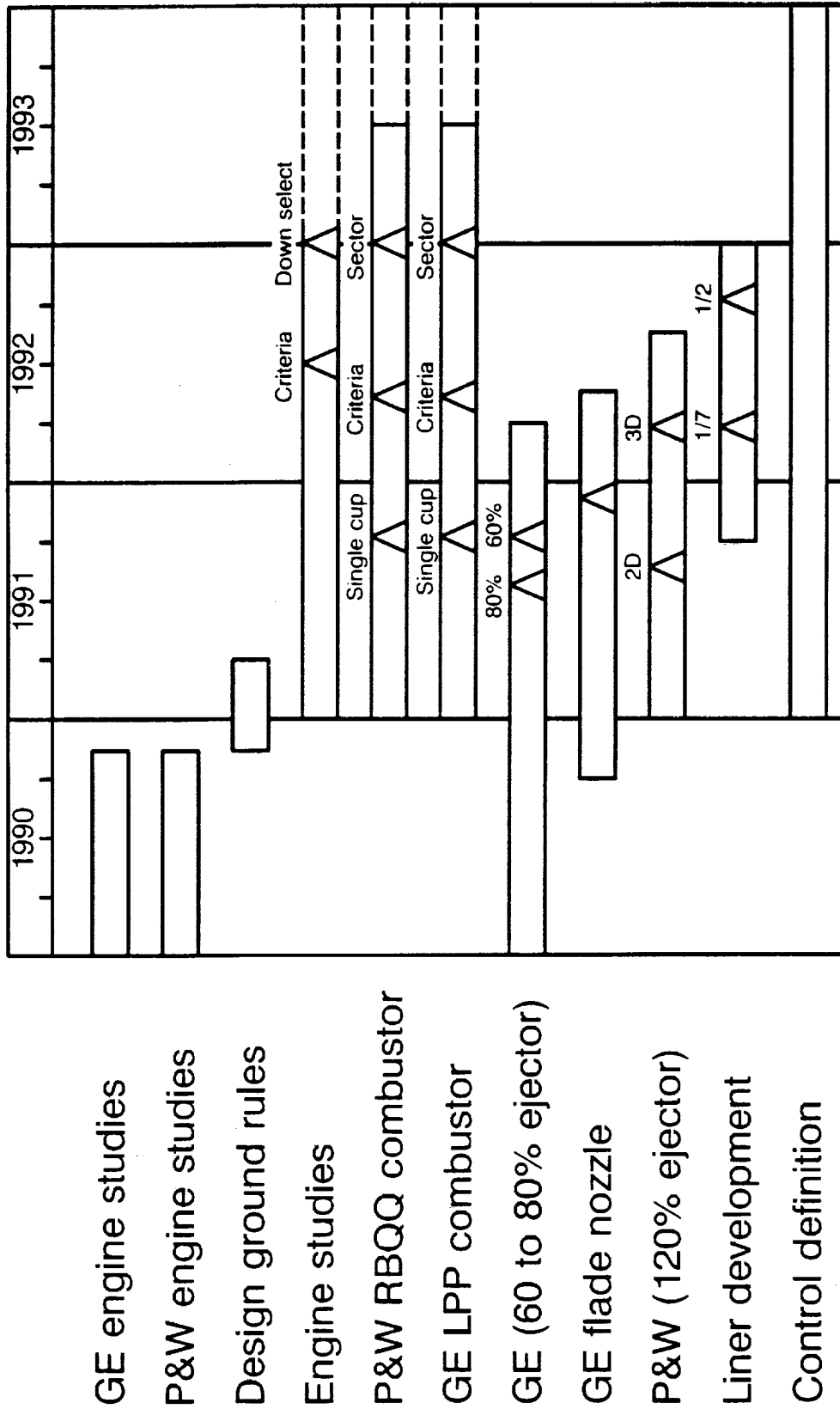
Over the next 2 years, P&W and GEAE are focused on demonstrating progress in addressing the environmental issues and establishing an economically viable, baseline propulsion system. The team plans to:

- Demonstrate 3 to 8 gm/kg NO_x in single cup combustor tests.
- Demonstrate the full range of low emission combustor operation in sector tests
- Demonstrate in scale model testing, practical exhaust nozzle concepts
- Demonstrate in scale model testing, acoustic lining material systems for use in the exhaust nozzle

In addition, the team plans to:

- Define inlet, engine, and exhaust nozzle design criteria and risk elements
 - Analytically model exhaust nozzle/wing interaction (impact on entrainment) and propulsion pod/wing interactions
 - Select a baseline engine/exhaust nozzle concept with backups
 - Identify a "slave" engine from existing assets for HSR Phase II technology validation testing
-

1992 Goals



1992 Goals

- Demonstrate 3 to 8 gm/Kg NOx in single cup test
- Demonstrate full range of combustor operation in sector test
- Define combustor design criteria and risk elements
- Demonstrate “practical” exhaust nozzle concept (noise and performance)
- Identify “realistic” acoustic lining approach
- Model exhaust nozzle/wing interaction (entrainment)
- Define engine/exhaust nozzle design criteria and risk elements
- Select baseline engine/nozzle and backup(s)
- Identify demo engine from existing assets

Design Ground Rules - Engine Evaluation

The P&W and GEAE design team has developed a set of design groundrules to use as the basis for developing the engine cycles and preliminary designs. This set of groundrules is essential to making a meaningful comparison of the various engine and exhaust nozzle combinations previously identified. All of the new designs are being developed using these assumptions. By the end of 1991, the team will be able to objectively compare the various engines and establish criteria for downselect to a baseline and backup. Elements of risk are to be determined for each of the engines in this process.

Design Ground Rules - Engine Evaluation

Airflow size	650 lb/sec
Thrust class	50 to 60,000 lb
Mach number	2.4
Cycle temperatures	2900°F max T41 1250°F max T3
Component efficiency	Late '90s technology availability
Materials	Late '90s technology availability
Commercial life	18,000 hrs/9,000 cycles cold section 9,000 hrs/4,500 cycles hot section

*P&W and GE Design Teams Are Defining Engines to
Common Set of Assumptions*

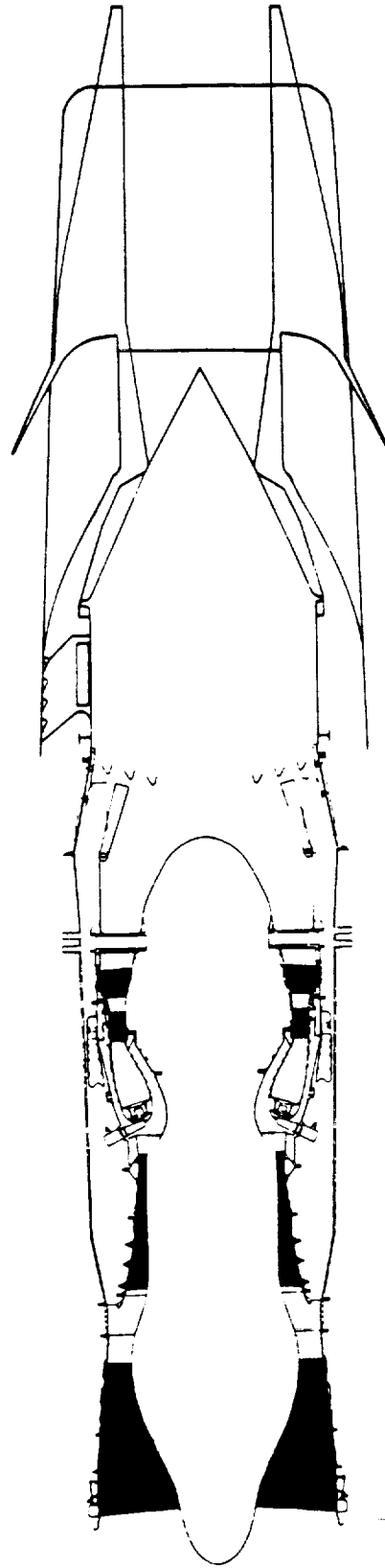
P&W Mixed Flow Turbofan

The P&W Mixed Flow Turbofan is a low bypass ratio turbofan with an overall pressure ratio of 20. The data reflects the common design groundrules. Engine preliminary design weights are still being developed.

GE Mixed Flow Turbofan

The GE mixed flow turbofan engine is a low bypass ratio turbofan with an overall pressure ratio of 21.5. This engine is shown with a 2D-CD ejector nozzle with 60% secondary flow entrainment. Nozzle thrust coefficients are based on this exhaust nozzle. The cycle and preliminary design activity on this engine is due to be completed in the next two months.

GE Mixed Flow Turbofan

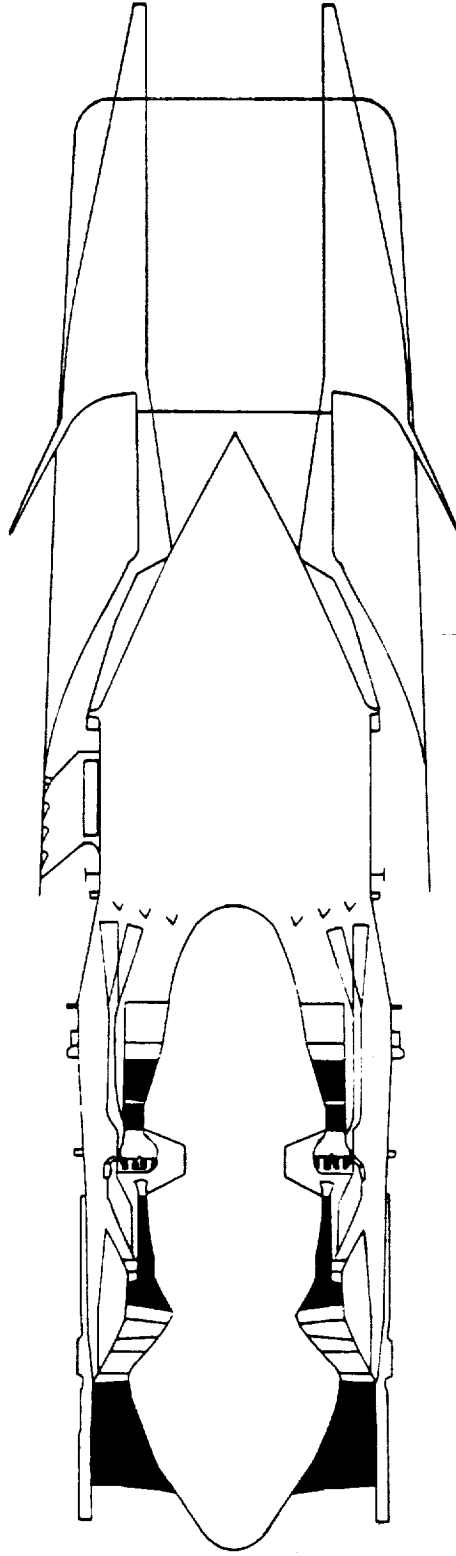


FPR	4.75		SFC subsonic	TBD
PROA	21.5		SFC supersonic	TBD
BPR	0.15		T41 cruise	TBD
Weight	- Core	TBD	T3 cruise	TBD
	- Exhaust nozzle	TBD	Cfg cruise	.982
	- Total	TBD	Cfg takeoff	.95

GE Variable Cycle Engine

The GE variable cycle engine is a double bypass engine with an overall pressure ratio of 25 and a bypass ratio of 0.65. The data shown is based on earlier design groundrules. We are in the process of updating this design to reflect the common design groundrules. This engine is shown with a 2D-CD ejector nozzle with 60% secondary flow entrainment.

GE Variable Cycle Engine



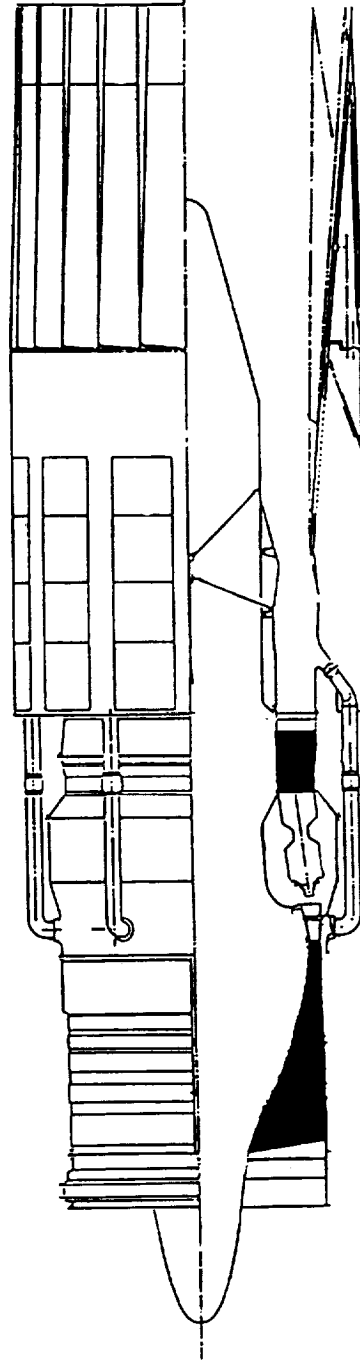
FPR	4.8	SFC subsonic	.90
PROA	25	SFC supersonic	1.24
BPR	0.65	T41 cruise	2750°F
Weight	- Core	T3 cruise	1200°F
	- Exhaust nozzle	Cfg cruise	.986
	- Total	Cfg takeoff	.93

This data is based on GE design ground rules. Engine design is being updated in 1991 to common design groundrules

P&W Turbine Bypass Engine (TBE)

The P&W Turbine Bypass Engine is a single spool turbojet with a bleed system around the turbine. It has an overall pressure ratio of 19. An axisymmetric ejector exhaust nozzle with 120% secondary flow entrainment is shown. Engine and exhaust nozzle preliminary design weights are still being developed.

P&W Turbine Bypass Engine (TBE)

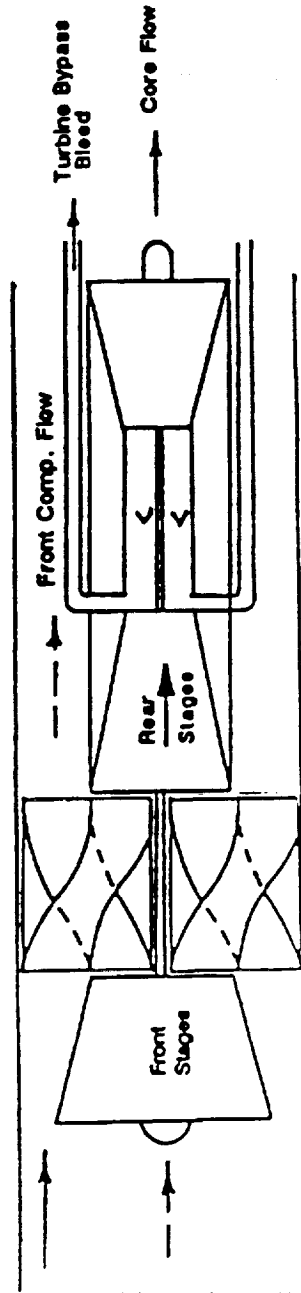


FPR	—	SFC subsonic	.93
PROA	19.0	SFC supersonic	1.29
BPR	—	T41 cruise	2700°F
Weight	- Core	T3 cruise	1250°F
	- Exhaust nozzle	Cfg cruise	.982
	- Total	Cfg takeoff	.95

P&W Turbine Bypass Engine with Inverted Flow Valve

The P&W Turbine Bypass Engine with inverted flow valve is a high flow engine cycle similar to the flade engine. At takeoff the engine operates like a separate flow turbofan with moderate bypass. At cruise the engine operates like a turbojet with all flow though both sections of the compressor. A fluid shield type exhaust nozzle could be utilized on this engine. The preliminary designs are planned to be completed by the end of 1991.

P&W Turbine Bypass Engine with Inverted Flow Valve

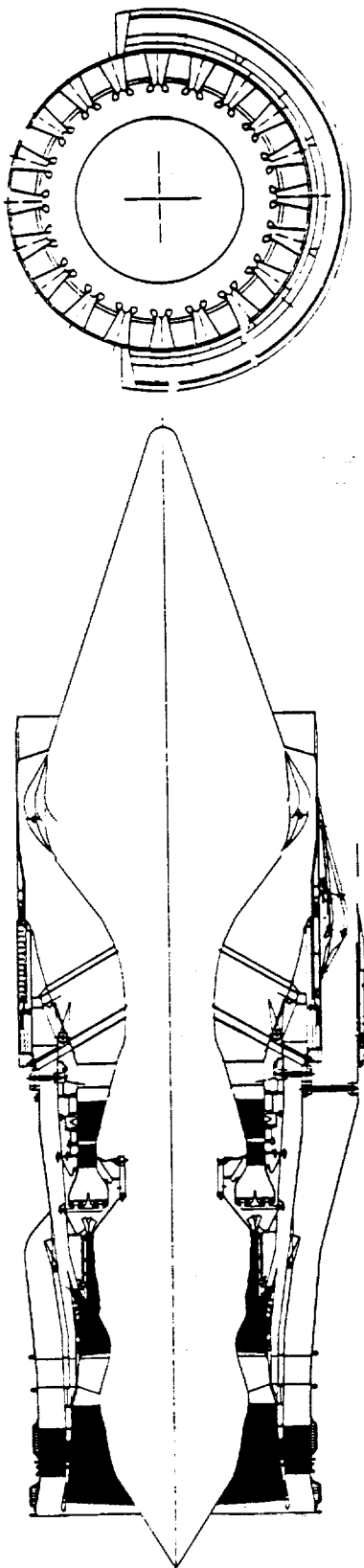


FPR	—	SFC subsonic	.93+
PROA	19.0	SFC supersonic	1.29+
BPR	—	T41 cruise	2700°F
Weight	- Core	T3 cruise	1250°F
	- Valve	Cfg cruise	.982
	- Exhaust nozzle	Cfg takeoff	.95
	- Total		

GE Fan on Blade (Flade)

The GE fan on blade or Flade engine is a double bypass engine with a tip fan on the second stage low pressure fan. The flade flow is ducted around the lower 220 degrees of the main exhaust to form a fluid shield around the exhaust. The flade operates with a higher bypass at subsonic cruise. The core engine is sized for supersonic cruise while the flade is sized for takeoff conditions. An axisymmetric exhaust nozzle with variable exit areas and minimum suppression on the core flow is being used. This data reflects the common design groundrules.

GE Fan on Blade (Flade)



FPR	4.95
PROA	21.7
BPR	0.33
Flade PR	1.8
Weight	- Core 8180
	- Exhaust nozzle 3805
	- Total 11,985

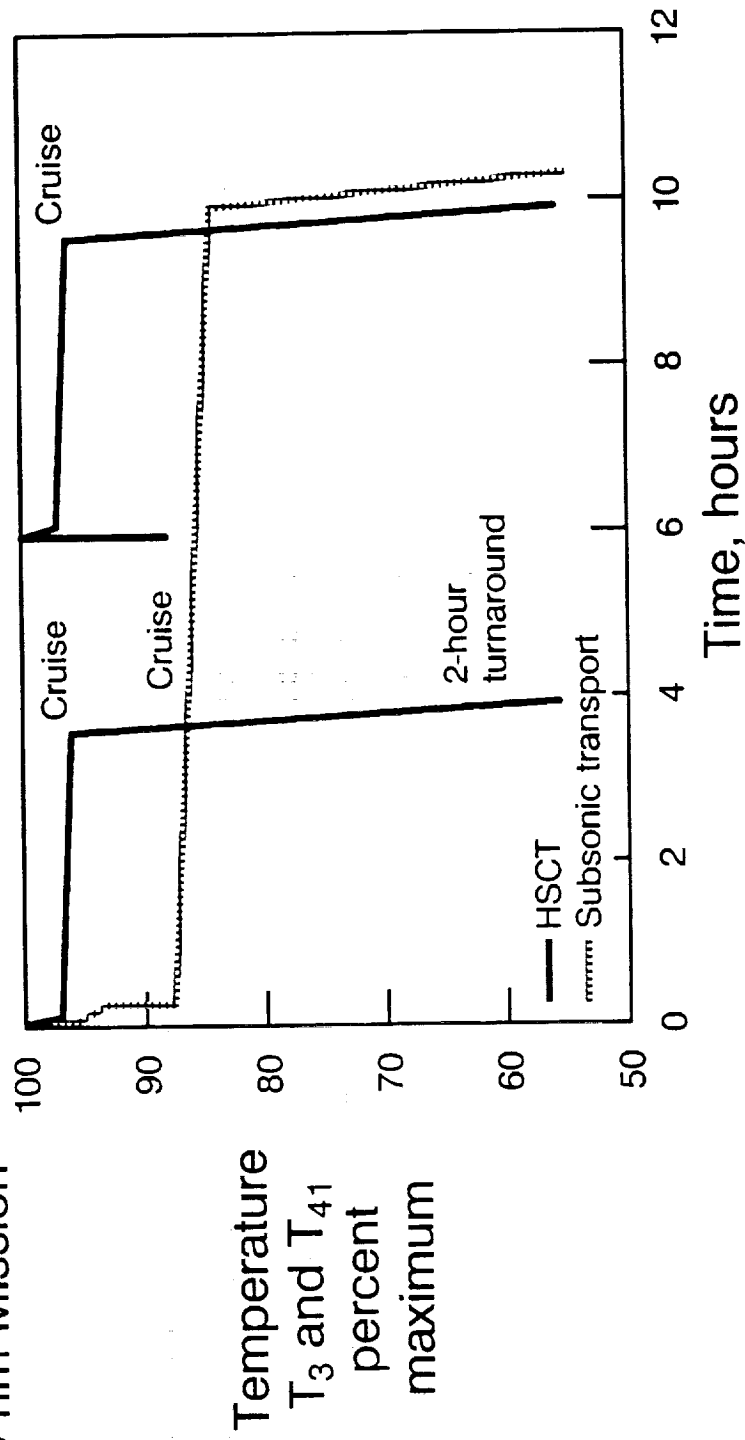
SFC subsonic	0.92
SFC supersonic	1.31
T41 cruise	2600°F
T3 cruise	1180°F
Cfg cruise	.982
Cfg takeoff	.95

HSCT Duty Cycle Significantly Different from Subsonic Transport

When assessing engine materials for the HSCT, the differences in the engine duty cycle relative to current subsonic commercial aircraft need to be addressed. This drives the need for advanced materials technology for both the compressor and hot sections of the engine. The HSCT will fly two legs for a comparable single leg in a subsonic airplane, doubling the temperature cycles per day. In addition, the HSCT engine will operate longer at temperatures closer to the maximum design temperatures both for the compressor and the turbine. Also, the HSCT hot section design temperatures are 20 percent higher than current subsonic engines and the inlet air temperatures are over 400°F hotter. To meet these goals, materials technology and/or additional cooling are required. Resorting to cooling is always detrimental to the engine specific thrust and specific fuel consumption and therefore is not a viable solution. Advancements in materials technology is the key.

HSCT Duty Cycle Significantly Different from Subsonic Transport

5000 nm Mission



- Twice as many cycles
- Sustained operation at higher temperatures

Candidate Materials

GEAE & P&W have developed a list of projected HSCT materials by engine component and have compared these projected materials to today's materials as shown in Table 2. On that basis, the HSCT appears to be the initial significant application of composite materials in a commercial aircraft engine. Ceramic matrix composites (CMC) and Intermetallic Matrix Composites (IMC) will be used extensively in the hot section and exhaust nozzle. Polymeric Matrix Composites (PMC) and Metal Matrix Composites (MMC) will be used in the front end of the engine for ducting, casings, and fan blisks.

Candidate Materials

Engine component	Today's technology	HSCT materials
<ul style="list-style-type: none"> • Fan blisks • Fan stator and case • Containment • High pressure compressor casing • Combustion liner • Combustor case • High pressure turbine nozzle • Turbine frame 	<ul style="list-style-type: none"> Ti alloy Ti alloy Nickel base alloy Waspalloy Hastelloy + TBC Waspalloy Nickel base alloy Waspalloy 	<ul style="list-style-type: none"> Ti MMC 700°F PMC 500°F fiber Ti Al 2400°F CMC Ti Al 2400°F CMC 2400°F CMC and waspalloy 2400°F CMC
<ul style="list-style-type: none"> • Exhaust nozzle liner, chutes and cascades • Exhaust nozzle structure 	<ul style="list-style-type: none"> Hastelloy + TBC Nickel base alloy + Ti alloy 	<ul style="list-style-type: none"> 2200°F IMC

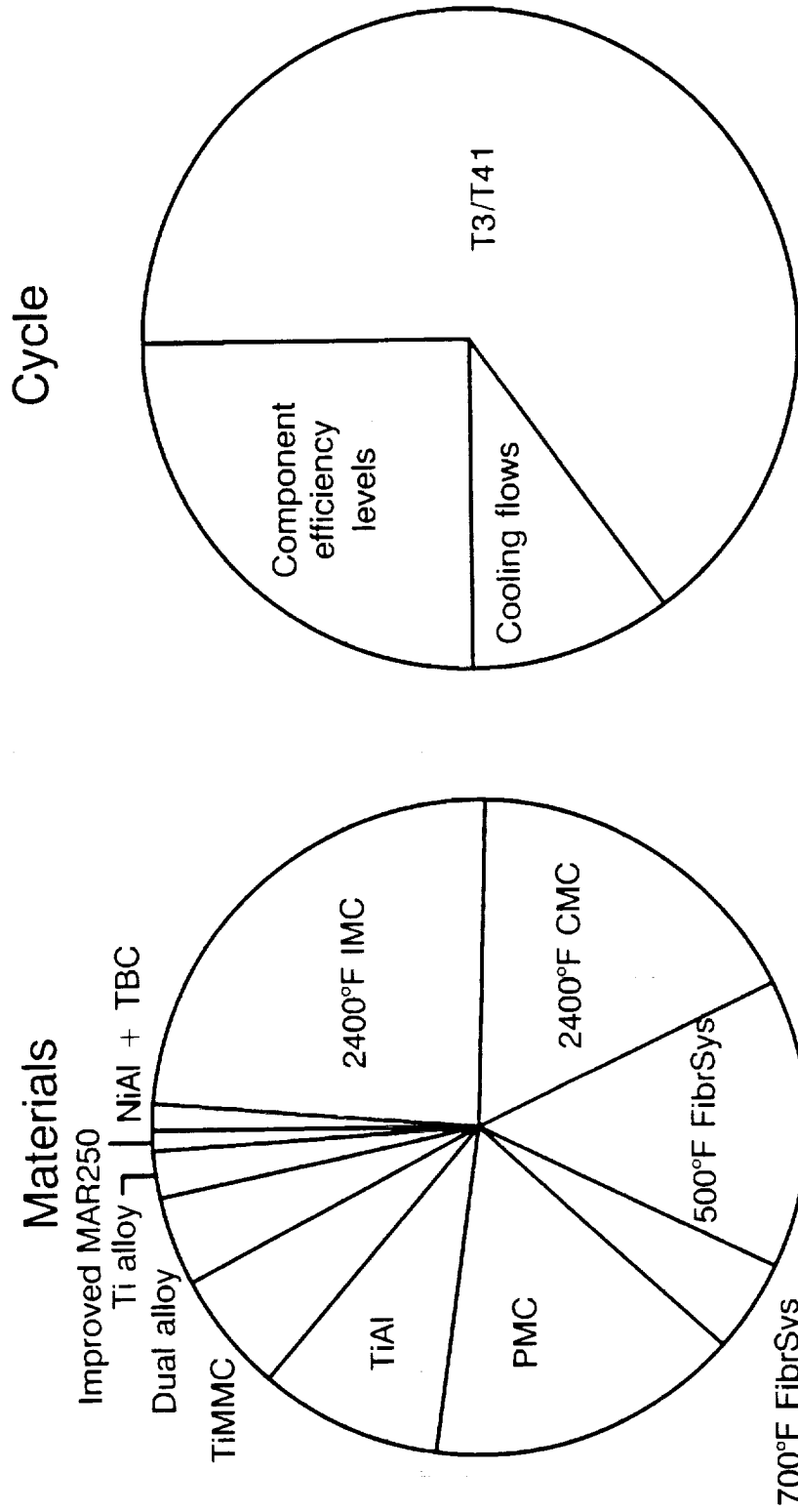
Initial Significant Application of Composite Materials

Material Technology Influence

Analysis has clearly indicated the importance of utilizing advanced materials in the engine. Relative to today's materials, propulsion system weight will decrease by over 24 percent and cruise performance will improve by 4 percent using these advanced materials. This weight decrease and performance increase has a major impact on the economics of the HSCT.

Advanced propulsion system materials impact the engine performance and, more importantly, propulsion system weight. When these improvements are cycled through the aircraft designs, the result is a lighter weight aircraft with reduced drag, therefore a smaller, lighter propulsion system is required. The result is a significant reduction in both acquisition cost of ownership (smaller airplane) and fuel burn.

Material Technology Influence

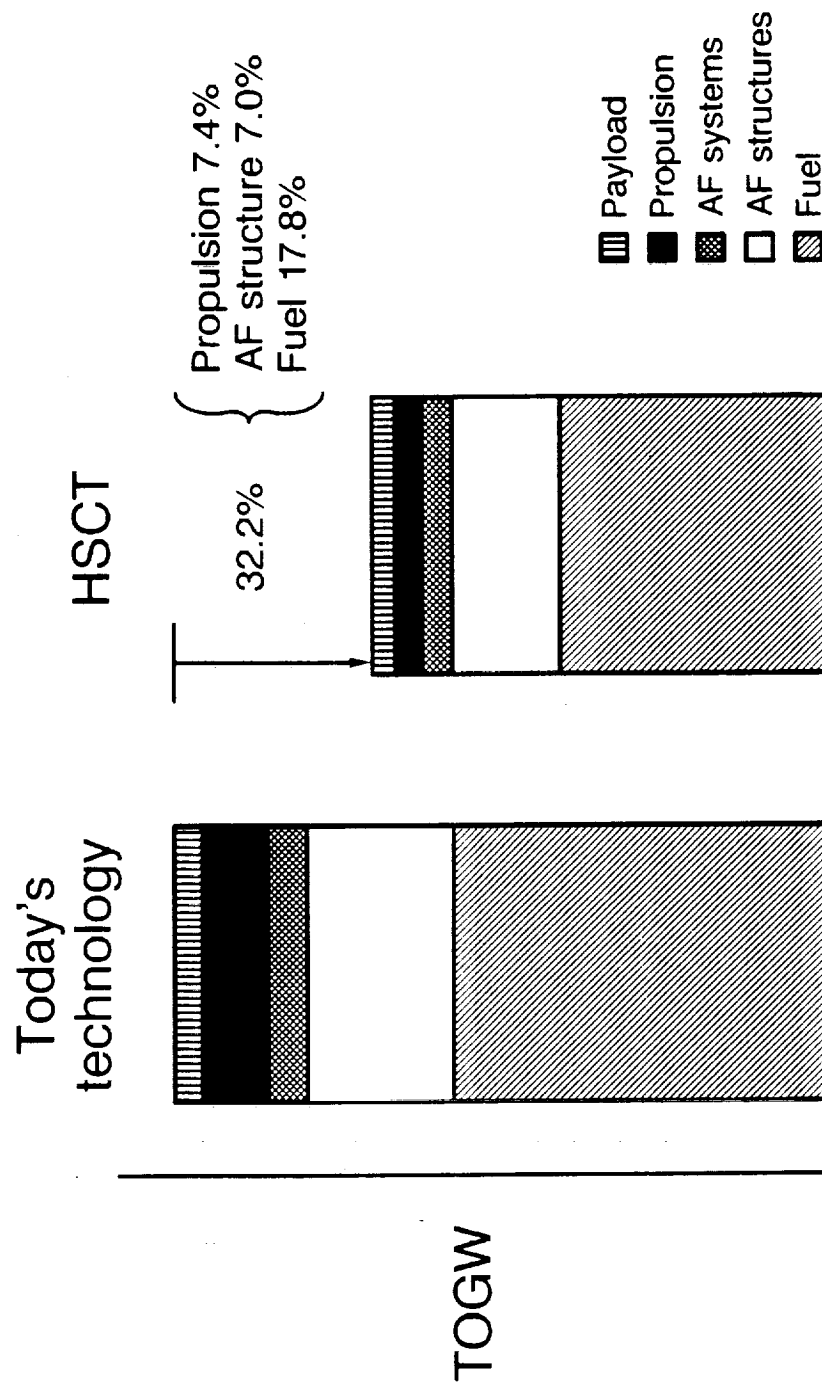


Propulsion Technology Impact on TOGW (5,000 n.m. Mission)

A measure of the economic challenge of the HSCT is to develop a design capable of payload fractions approaching that of subsonic aircraft. A supersonic aircraft with a payload fraction significantly lower than current subsonic aircraft operates at a significant competitive disadvantage, requiring premium fare structures to make a profit. A payload fraction approaching 7.5 to 10 percent is viewed as a reasonable goal to assess the economic competitiveness of the aircraft design. The takeoff noise requirements have a negative impact on our current configuration's ability to reach the target. The incorporation of advanced materials and aerothermal cycle improvements have helped us get close to our payload fraction target. We have made progress since Concorde and must continue to strive to improve the HSCT propulsion system designs to increase the airplane's payload fraction.

Comparing today's technology propulsion system with an HSCT propulsion system designed for entry into service in the year 2005, it is clear that significant progress is being made. With the same payload, the TOGW of the HSCT is projected to be over 32 percent lower than that available with today's engine technology. In the analysis, the improvement is totally a function of the propulsion technology as the operating characteristics and level of structural technology of airplane were not changed. The reduced TOGW is a function of the improved specific fuel consumption of the engines, improvements in acoustic suppression technology, and the reduction in engine weight as a result of the incorporation of advanced materials.

Propulsion Technology Impact on TOGW (5,000 n.m. Mission)



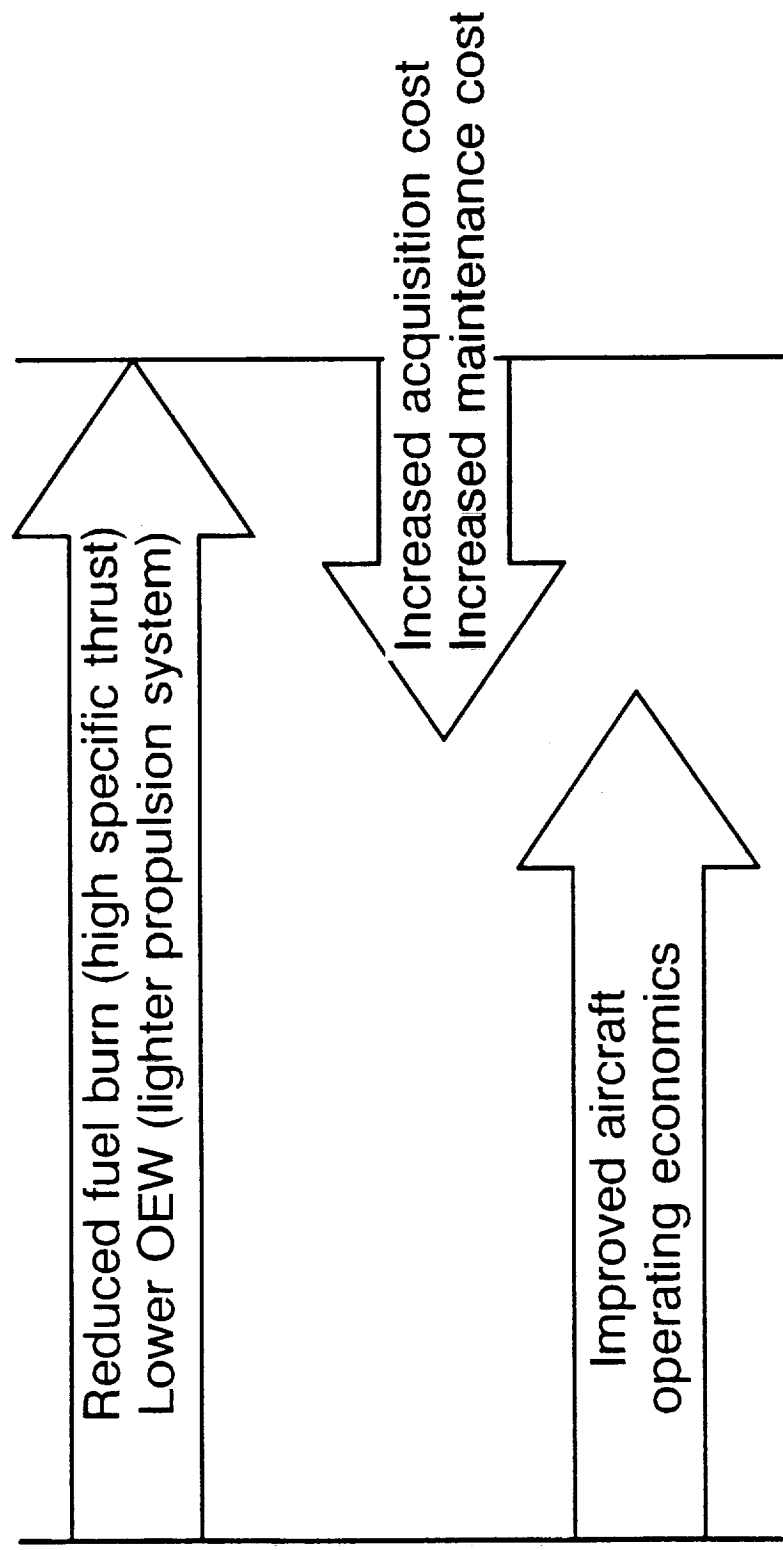
Engine Materials Impact

Advancements in engine materials technology are expected to have a major impact on the overall economic viability of the HSCT. The use of advanced engine materials can reduce the block fuel burn through increased efficiency via higher operating temperatures and smaller size via increased specific thrust of the engines. Advanced materials also lower Operating Empty Weight (OEW) of the airplane through lighter weight propulsion systems. A reduction of 1 pound of total propulsion system weight reduces the aircraft weight by 24 pounds for a 4 engine HSCT. The benefits need to be weighed against the increased acquisition and maintenance costs associated with the incorporation of advanced materials in the engine designs. This assessment needs to be done at the component and subcomponent level and evaluated at the aircraft level in order to verify the ultimate economic value to the system.

One of the key uncertainties is the acquisition cost of the advanced propulsion system materials. They require a new manufacturing base devoted to nonmetallic composites using innovative processing concepts for fiber/matrix distribution and intelligent processing. Raw material cost may be lower and new suppliers may emerge. Significant investment in new plant, equipment, and processes is needed in the 1990's to make these materials a commercial reality.

The economic viability of an aircraft is a balance between airplane cost and commercial value. In this day of rapidly changing technology and world conditions, it is important to recognize that operating costs are critical from an airline's point of view. Airlines cannot afford to purchase technology for technology's sake. Technology must not only improve the productivity of the aircraft but also contribute to reducing operating expenditures such as fuel and maintenance costs. Also, the manufacturers cannot ignore the costs of ownership-depreciation, interest, and insurance in developing any new transportation system.

Engine Materials Impact



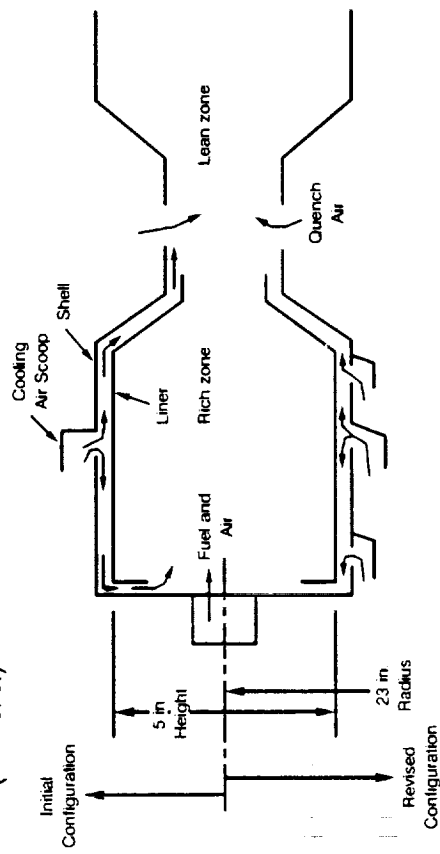
*Utilization of Advanced Propulsion Materials Contribute
Significantly to Economic Viability Goals of HSCT*

Low Emission Combustor Concepts

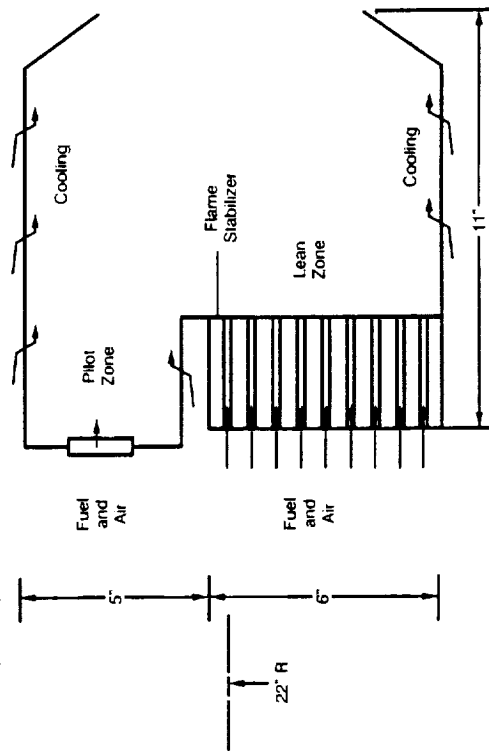
P&W and GEAE have been looking at several advanced combustor concepts capable of meeting the NASA goal of 5 grams NO_x per kilogram of fuel burned. These combustor concepts are based on combustion occurring in either the lean or rich condition. There are significant engineering challenges associated with controlling combustion at these conditions. When operating lean, combustion in occurring near the stability limit raising the operability issue of "blow out." There is also the risk of premixing duct flashback and autoignition. When operating rich, the combustion liner cannot use conventional film cooling as the introduction of cooling air will alter the combustion process away from the rich condition. The combustion liner must therefore be convection cooled requiring advanced high thermal conductivity and high temperature materials. In addition, the remainder of the fuel from the rich combustion must be quickly quenched (in around 1 millisecond) to the lean condition in order to complete the combustion with minimum NO_x formation. Research is underway on both approaches starting with flame tube testing in 1990 leading to combustor rig testing in 1991 and 1992. These advanced combustor concepts do not have a major impact on the overall economics of the airplane. They are similar in size to conventional combustors and operate with similar fuel efficiencies.

Low Emission Combustor Concepts

Rich Burn, Quick Quench (RBQQ)



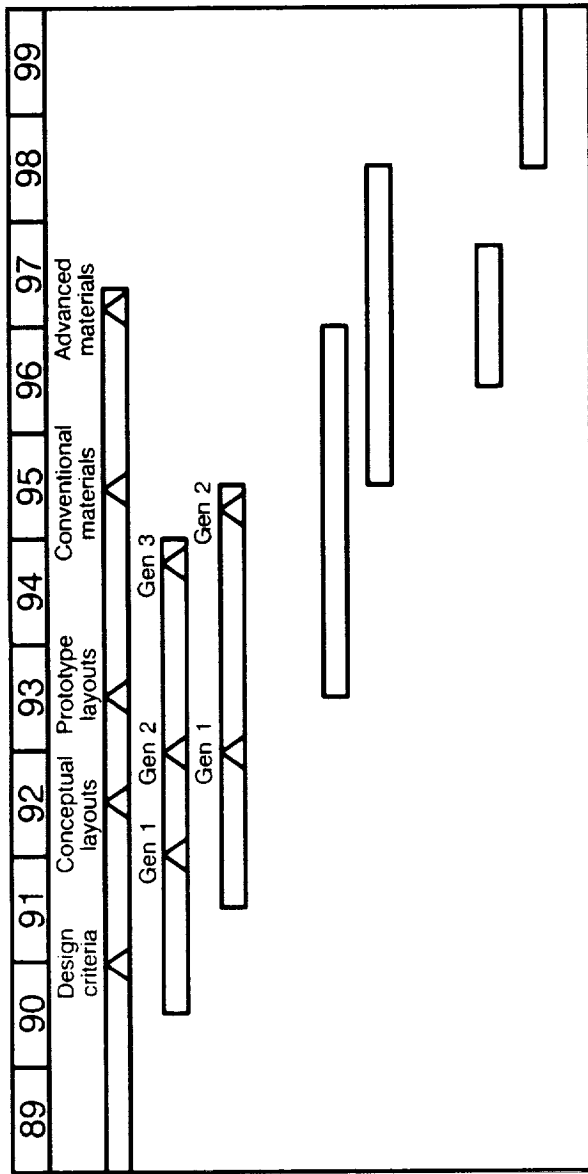
Lean, Premixed, Prevaporized (LLP) Combustor



HSCT Low Emission Combustor Status

The low emission combustor work is focused on progressively demonstrating 3 to 8 gm/kg NO_x in single cup, sector, annular, and finally engine testing. Two prime combustor concepts are being investigated, the Rich Burn Quick Quench (RBQQ) and the Lean Premixed Prevaporized (LPP). Both concepts are to be taken into sector and possibly annular testing. Only one of the concepts is planned to be taken to engine testing. Ceramic Matrix Composites (CMC) materials being developed in NASA's Enabling Propulsion Materials Program will feed into the combustor development program at the end of 1997 with annular testing in 1998 and engine testing in 1999. Test results to date from cold flow mixing test and hot rig testing at NASA are encouraging.

HSCT Low Emission Combustor Status



Design

Mixer tests

Sector combustor

Annular combustor

- Conventional materials
- Advanced materials

Engine test

- Conventional materials
- Advanced materials

Accomplishments

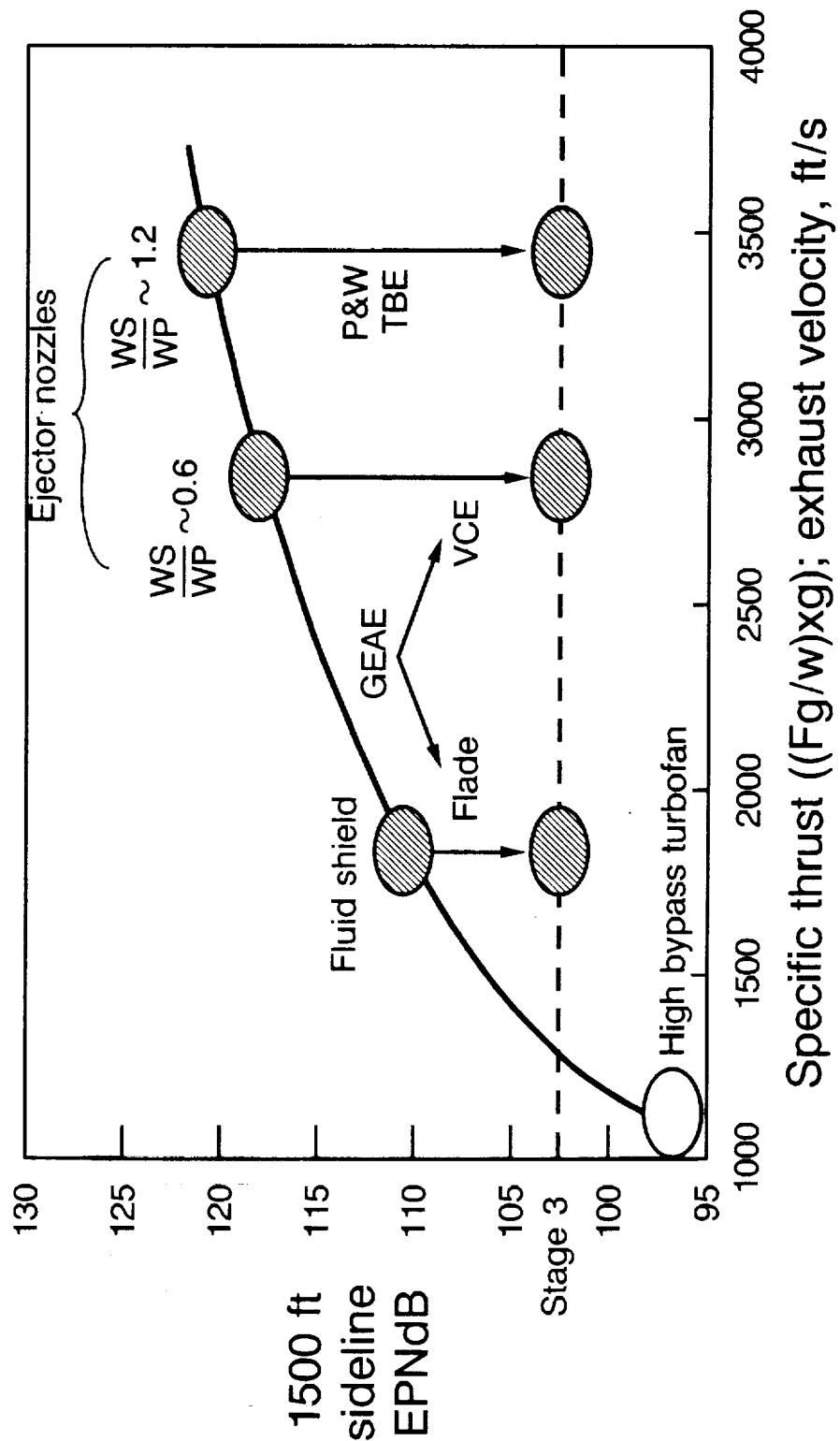
- Predicted benefits of advanced materials and variable geometry
- Assessed/developed analytical capabilities for combustor design (CFD, chemical kinetics)
- Conducted cold flow mixing tests to identify preferred fuel injection location and verify CFD predictions
- Developed improved diagnostics (NO₂ LIF and laser Raman) for combustors
- Initiated single cup rig tests to demonstrate 3-8 g/kg NO_x

Two Basic Noise Reduction Approaches

Two different approaches to noise reduction are being investigated. One involves breaking the jet into many smaller jets, high levels of ambient air entrainment, and acoustically treated panels for high frequency noise absorption. The second approach involves reducing the jet velocity via additional airflow through the engine, some ambient air entrainment, and mean shear reduction for high frequency noise absorption. Acoustic model testing of several promising concepts is being conducted in 1991. This testing will provide key input into the propulsion system selection process for the HSCT.

Two Basic Noise Reduction Approaches

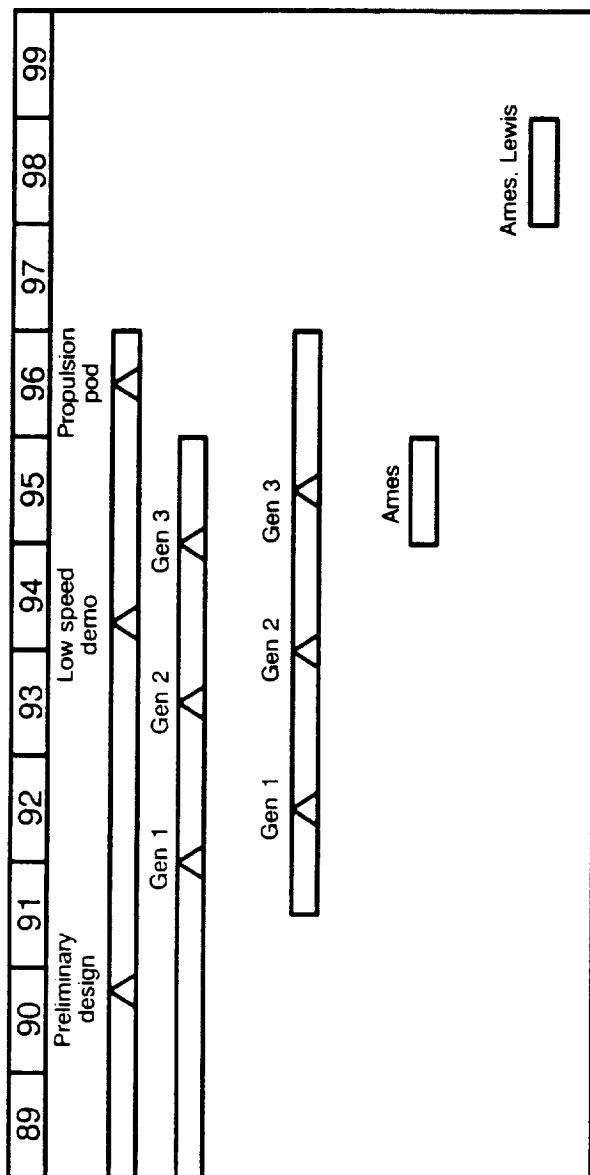
- High flow engine + modest noise reduction
- High specific thrust engine + aggressive noise reduction



HSCT Exhaust Nozzle Status

The HSCT exhaust nozzle technology development involves significant aerodynamic and acoustic scale model testing. Initial screening tests are planned to be completed by the end of 1991 to evaluate the various approaches to noise reduction. Enhanced computational capability is being used in the exhaust nozzle designs. Exhaust nozzle acoustic lining has been identified as a critical technology and plans are underway to begin to develop this technology. The need for an early large scale exhaust nozzle test to verify the scale model results has been identified. Testing is planned to be conducted in the Ames 40 x 80 wind tunnel. A second large scale test incorporating a second or third generation exhaust nozzle is planned for 1998. This nozzle will be tested in the Lewis 10 x 10 supersonic tunnel, in addition to the Ames facility.

HSCT Exhaust Nozzle Status



Accomplishments

- Preliminary designs of 3 exhaust nozzle systems
- Tested 2 high entrainment ejector concepts
- Initiated 3 additional generation 1 model test programs for 1991
- Assessed/developed analytical tools for nozzle design (aero and acoustics)
- Identified acoustic lining as critical technology
- Utilized ANOPP to evaluate aircraft takeoff noise and impact of operational procedures and aircraft low speed performance

Take-off Noise Impact

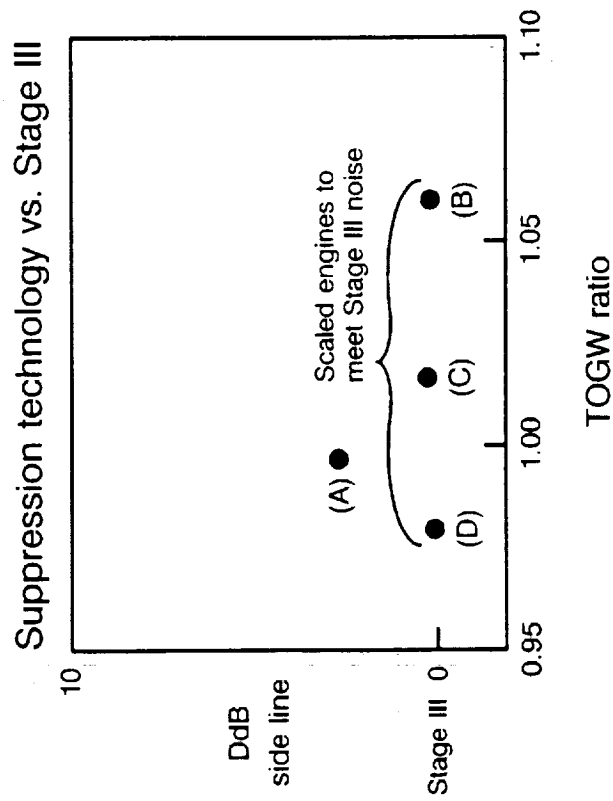
Our current studies indicated that FAR 36 Stage III noise requirements can be met with projected exhaust nozzle suppression technology and modifications to the aircraft takeoff profile without oversizing the engine. The projected sideline noise for an engine design with an exhaust velocity of 2800 feet per second and 50,000 pounds of thrust is approximately 2.5 dB above FAR 36 Stage III, assuming no changes in takeoff procedures. In order to meet Stage III, the engine size was increased by 19 percent dropping the exhaust velocity to 2590 feet per second. This increase in engine size, when factored into the aircraft design, increased the TOGW by 6.4 percent as noted by point B.

Several avenues of improvements outside the exhaust nozzle can be explored to further reduce the aircraft TOGW while maintaining the noise level at FAR 36 Stage III. The takeoff profile can be modified by setting a higher power during ground roll where ground attenuation reduces the noise. This higher powered ground run requires a thrust reduction at the 35-foot obstacle in addition to the cutback at 689 feet altitude allowed under the current regulations. This modification to current fixed throttle requirements in the FAR can reduce aircraft TOGW by nearly 4 percent as noted by point C.

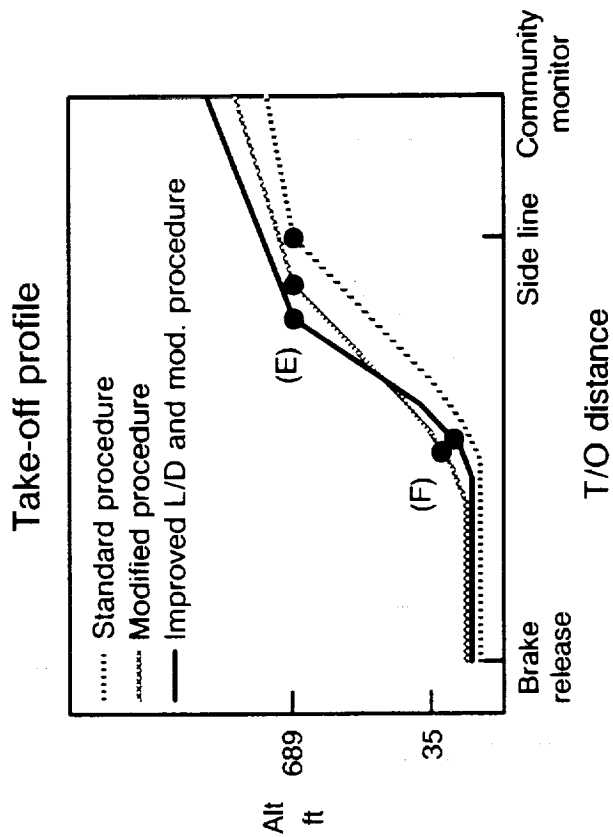
Improvements in aircraft takeoff performance could further reduce the TOGW. Based on NASA wind tunnel work an 18 percent improvement in takeoff L/D is possible. This can reduce the TOGW by another 4 percent as shown in point D. At point D, the aircraft is smaller than the original baseline designs by 1.5 percent while still meeting the noise goals.

Take-off Noise Impact

Projected suppression technology can meet Stage III with modifications to the take-off profile



- (A) Current baseline design
- (B) Standard T/O profile
- (C) Modified T/O profile
- (D) Modified T/O profile and improved L/D



- (E) Standard noise abatement thrust cut back (689 ft)
- (F) Thrust roll-back

Summary

The technology developments needed to address the environmental issues of airport noise and engine emissions represent the threshold level for a viable program. These technologies must be introduced in concert with the propulsion system materials technologies and other aircraft technologies to reduce both the cost of ownership and the direct operating cost of the HSCT. They are key to the environmental compatibility and economic viability of a HSCT for entry into service in the year 2005.

GEAE & P&W are encouraged by the technical progress being made toward addressing the propulsion system-related environmental challenges and the improvements in the HSCT system economics. There is, nevertheless, a great deal of work required to turn the promises of today into tomorrow's reality. As we in the propulsion industry continue to work the technology areas, we must ask ourselves if the economics are good enough to launch an engine development program. The technical and commercial risks will need to be assessed in much greater detail in order to answer this question. We are hopeful that it can be answered in the positive by the late 1990's in order to make the HSCT a reality in the year 2005.

Summary



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Session I. Plenary Session

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NASA Headquarter's Summary Reports

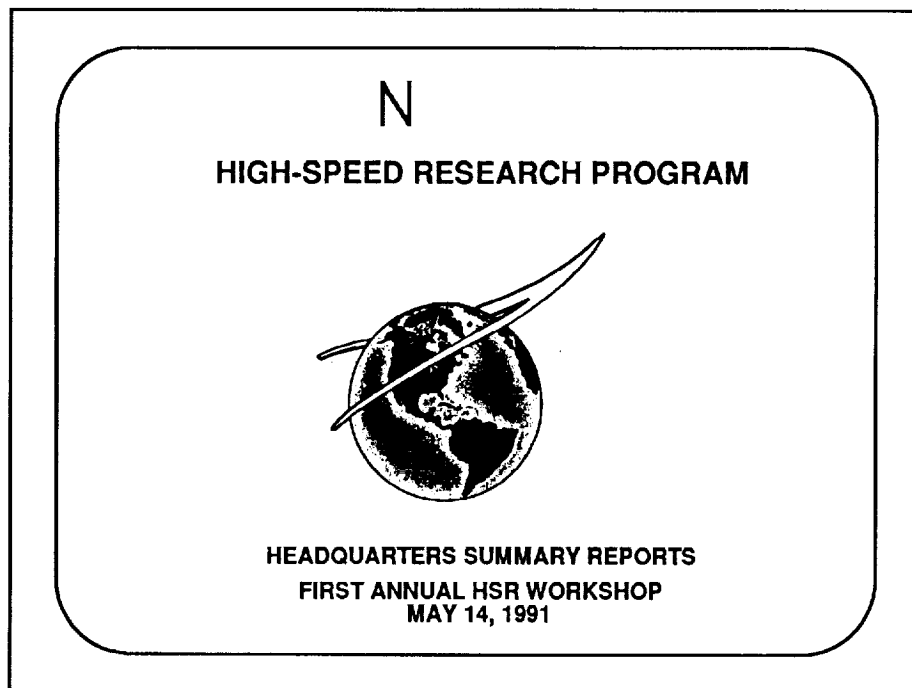
Howard L. Wesoky, Code RJ, Dr. Michael J. Prather, Code EEU, John R. Facey, Code RP, George F. Unger, Code RF, and Samuel L. Veneri, Code RM

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55-05
12020**HEADQUARTERS SUMMARY REPORTS**

The purpose of this report is to summarize the status of the NASA sponsored involvement in high-speed civil transport research and technology, including major cooperative efforts. Of course, that involvement is currently focussed on the High-Speed Research Program.



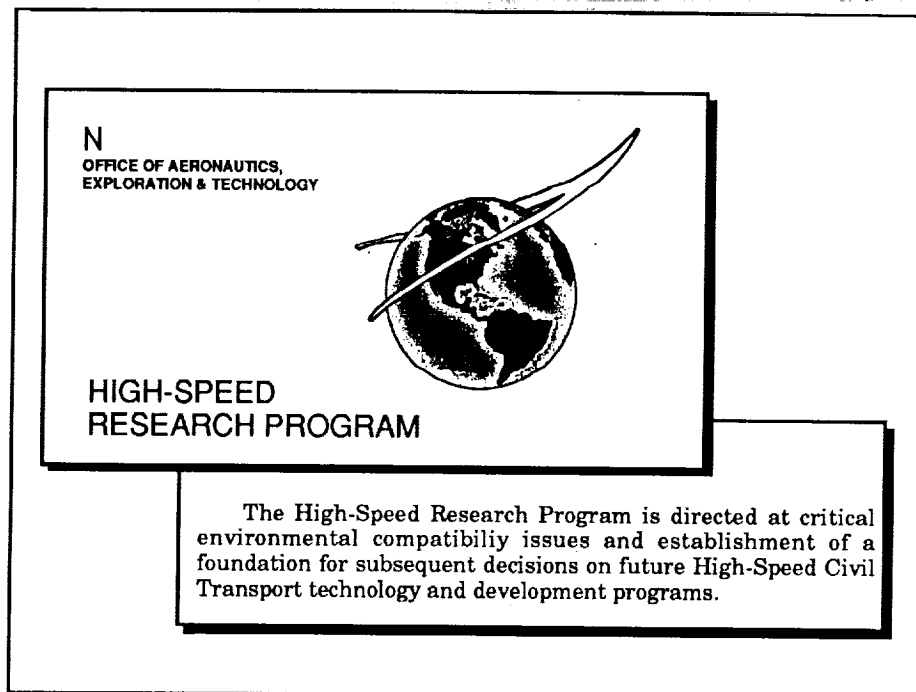
HIGH-SPEED RESEARCH PROGRAM

The White House Office of Science and Technology Policy (OSTP) reports of 1985 and 1987 identified national aeronautical R&D goals directed at maintenance of U.S. aeronautical preeminence into the next century, and presented an action plan for achievement of the goals.

The goals address three areas of aeronautics -- subsonics, supersonics, and transatmospherics. The supersonics goal calls for development of technology for efficient, long-distance supersonic cruise for both future military aircraft and trans-Pacific-range supersonic transports.

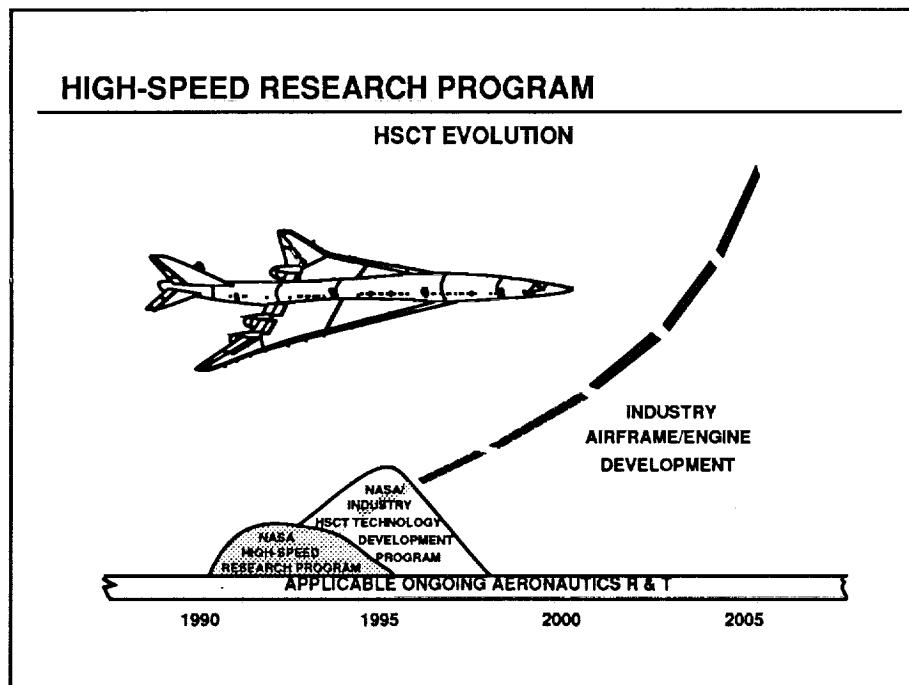
Consistent with this goal, and in view of the world market potential and international competition, the development of an updated technology base for high-speed civil transports -- with top priority and emphasis on the environmental barrier issues -- is an important and timely national research objective.

The NASA High-Speed Research Program is a direct response to meeting this national objective. It is an essential step which must be taken prior to initiating more focussed government/industry technology development efforts that could lead to future high-speed civil transports (HSCT). A principal challenge in this initial effort is to balance the often conflicting requirements of environmental compatibility and economic viability.



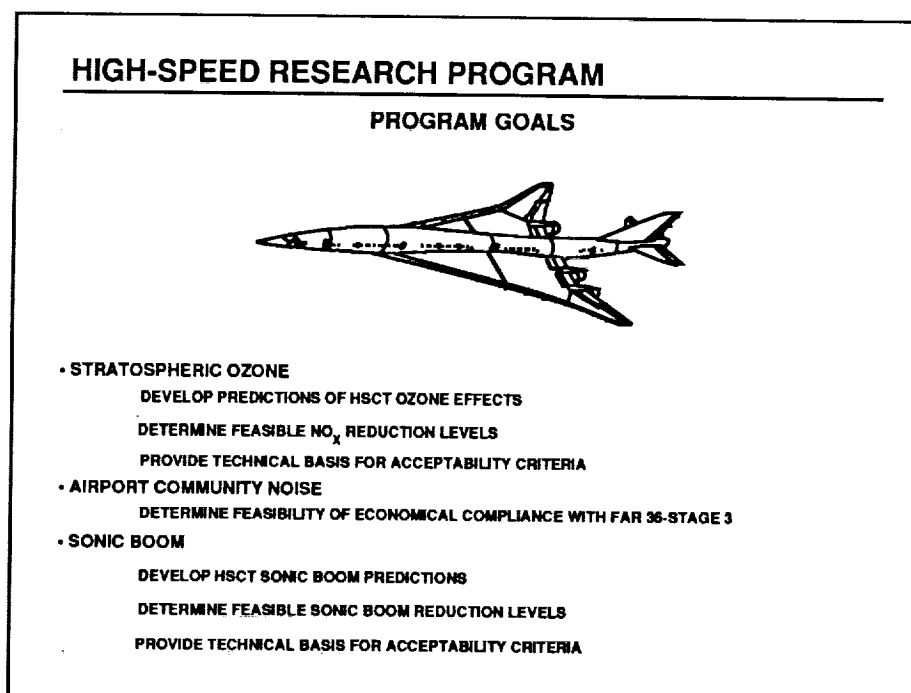
HSCT EVOLUTION

The High-Speed Research Program (HSRP) is the first phase of a larger planned NASA technology development program. If solutions are identified for the barrier environmental problems, and system studies continue to indicate promise of economic success, a cooperative NASA and industry focussed technology program could begin, possibly in FY 93, that would complete a foundation for more costly airframe and engine development and production by the industry.



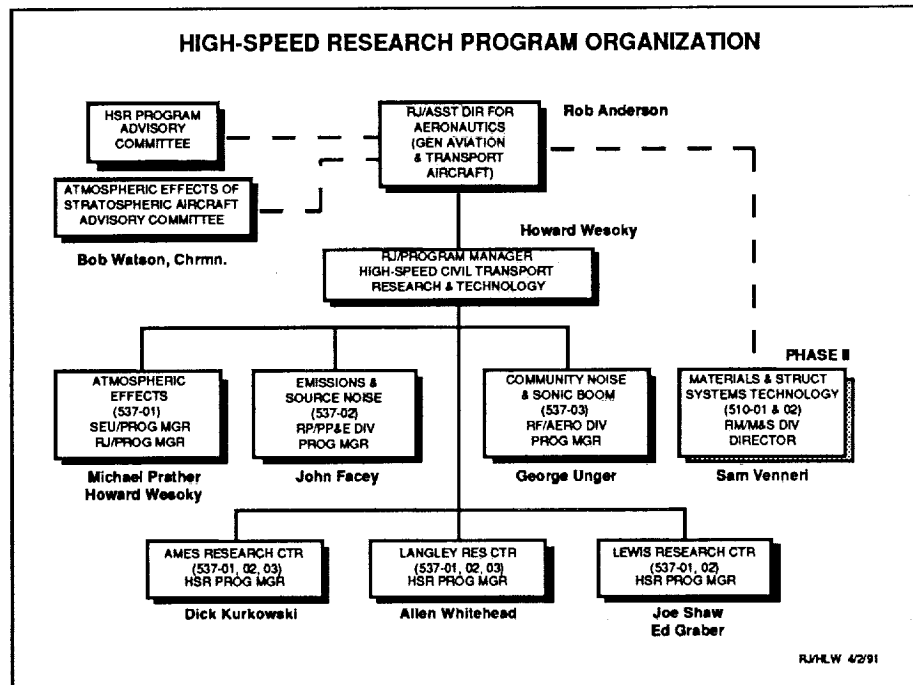
PROGRAM GOALS

Acceptable levels of ozone depletion or sonic boom are not currently known, and definition of acceptability is a regulatory and political process. The HSRP goal is to provide technical bases for acceptability criteria. Community noise is currently regulated, and it seems clear that HSCT aircraft will have to comply with at least the spirit of the current subsonic constraint, FAR 36, Stage 3.



HIGH-SPEED RESEARCH PROGRAM ORGANIZATION

Under the supervision of the Assistant Director for Aeronautics (General Aviation & Transport Aircraft) in the Office of Aeronautics, Exploration and Technology (OAET), responsibility for implementation of the HSRP is assigned to the Program Manager, HSCT Research & Technology to coordinate preparation of budgets and plans, monitor overall progress, and provide reports to OAET management. Headquarters management responsibility for specific disciplinary areas (i.e., RTOPs) of the HSRP are assigned to OAET and Office of Space Science & Applications program managers. Implementation of activities in the field is coordinated by Center HSR Program Managers. Two advisory committees assist in guiding the overall program and the atmospheric science assessment activity. Related HSCT materials and structures technology is currently being developed in a parallel systems technology program which is broad in scope, and is a precursor for the next phase of the HSCT technology foundation (aka Phase II).



PROGRAM SUMMARY

The Headquarters managers will summarize the program status using a format which is similar to the program work breakdown structure. The NASA systems studies will not be covered here, as that work is primarily accomplished by the aircraft and engine manufacturers whose summary reports are provided elsewhere.

PROGRAM SUMMARY

• INTRODUCTION	HOWARD WESOKY
• ATMOSPHERIC EFFECTS OF STRATOSPHERIC AIRCRAFT	MICHAEL PRATHER
• LOW NOx COMBUSTOR TECHNOLOGY	JOHN FACEY
• SOURCE NOISE REDUCTION	JOHN FACEY
• COMMUNITY NOISE REDUCTION	GEORGE UNGER
• SONIC BOOM MINIMIZATION	GEORGE UNGER
• SUPERSONIC LAMINAR FLOW CONTROL	GEORGE UNGER
• MATERIALS & STRUCTURES	SAM VENNERI
• WRAPUP & QUESTIONS	HOWARD WESOKY

MILESTONE SUMMARY

This is a summary of planned program milestones from the HSRP Briefing Book, which was utilized for budget advocacy. As the six-year program schedule is now about 25% complete, some changes in plans are naturally occurring (i.e., typical for research and development), and an objective of this workshop is to assess related progress. Some program elements have seemingly progressed better than others, but, on the whole, the HSRP appears to be achieving important goals.

HIGH-SPEED RESEARCH PROGRAM								
MILESTONE SUMMARY								
ELEMENTS	1990	1991	1992	1993	1994	1995	GOALS	
ATMOSPHERIC EFFECTS	ATMOSPHERIC STUDIES						ASSESS EFFECTS OF HSCT FLEET ON ATMOSPHERE	
	2-D MODEL ASSESSMENT	DETERMINE MODEL UNCERTAINTIES	IMPROVE MODELS	COMPLETE ASSESSMENT				
	SYSTEM STUDIES						PROVIDE BASIS FOR EVALUATING AND GUIDING TECHNOLOGY	
	BASIS CONFIGURATIONS	ENGINE CYCLE SELECTION	ASSESS CONFIGURATION ECONOMICS					
EMISSIONS AND SOURCE NOISE	EMISSIONS						DEVELOP TECHNOLOGY FOR ACCEPTABLE REDUCTION OF EMISSIONS AND NOISE	
	ADDITIVES EVALUATION	FLAME TUBE COMBUSTION TESTS	VALIDATE COMBUSTION ANALYSES	COMBUSTION VERIFICATION TESTS				
	NOISE REDUCTION							
	CONCEPTS ASSESSED	VALIDATE AEROACOUSTIC ANALYSES	VERIFY NOISE REDUCTION					
COMMUNITY NOISE AND SONIC BOOM	COMMUNITY NOISE / HIGH LIFT						VERIFY COMPLIANCE WITH FAR 36 STAGE 3 NOISE LEVELS	
	UPDATE NOISE CODE	VERIFY NOISE PREDICTION	LOW-NOISE AIRCRAFT W.T. TESTS					
	SONIC BOOM						ASSESS LOW BOOM CONCEPTS	
	EVALUATE ACCEPTABILITY CRITERIA	LOW-BOOM OPTIMIZATION	FLIGHT VALIDATION					
	SUPERSONIC LFC						DEVELOP SLFC TECHNOLOGY	
	TRANSITION GLOVE TEST	3-D FLOW TRANSITION PREDICTION	COMPLETE FLIGHT TEST					

MAJOR ACCOMPLISHMENTS TO DATE

The first interim assessment of HSCT atmospheric impact is now being documented, and important modeling and chemistry laboratory work is underway, along with planning for field measurements. Broad disciplinary application of computational fluid dynamics (CFD) has provided an analytical tool not available in previous SST efforts. In the propulsion area, important experimental confirmation of emissions and noise reduction has also been achieved. Wind tunnel tests of high lift devices have begun, and interesting piloted simulations are identifying related operational procedures for reducing community noise. Wind tunnel tests are also helping to confirm low sonic boom concepts, and subjective responses to the pressure signatures are providing additional guidance. For supersonic laminar flow control research (SLFC), preliminary design analysis and wind tunnel tests have been accomplished. The F-16XL aircraft which will be the focus for SLFC experiments is now at DFRF.

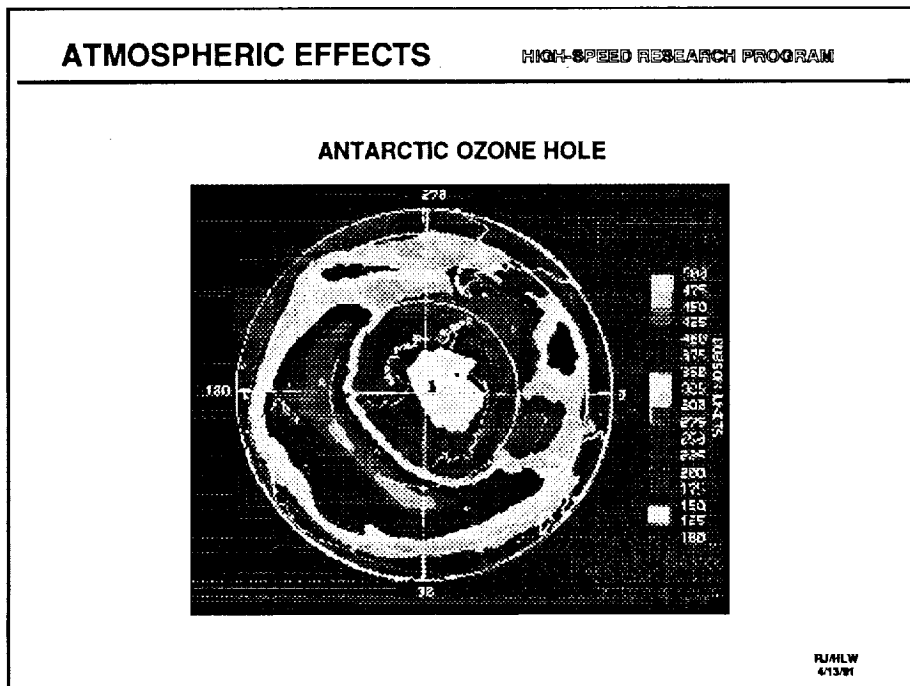
The major accomplishments for the related materials and structures research are provided later.

MAJOR ACCOMPLISHMENTS TO DATE

- **ATMOSPHERIC RESEARCH**
 - 2-D MODEL ASSESSMENT
 - CHEMISTRY LAB EXPERIMENTS
 - FIELD CAMPAIGN PLANNING
- **EMISSIONS REDUCTION**
 - ADDITIVES EVALUATION
 - CFD APPLICATION
 - FLAMETUBE DEMONSTRATION OF LPP CONCEPT
- **SOURCE NOISE REDUCTION**
 - CFD APPLICATION
 - MIXER/EJECTOR NOZZLE AEROACOUSTIC PERFORMANCE
- **COMMUNITY NOISE**
 - ANOPP APPLICATION
 - HIGH-LIFT CONCEPT SCREENING
 - PILOTED SIMULATION OF OPERATIONAL PROCEDURES
- **SONIC BOOM**
 - CFD APPLICATION
 - PHASE I LOW BOOM CONCEPT W.T. TESTS
 - SUBJECTIVE RESPONSE EVALUATION
- **SUPERSONIC LAMINAR FLOW CONTROL**
 - CFD APPLICATION
 - FLOW MEASUREMENT PROCEDURES
 - F-16XL AIRCRAFT ACQUISITION

ATMOSPHERIC EFFECTS

This well known plot of satellite data, which effectively pictures the Antarctic ozone hole, is representative of environmental concerns similar to those for HSCT operation in the stratosphere. Scientists from the NASA Upper Atmosphere Research Program (UARP), who have contributed to knowledge of CFC effects, are now applying this understanding to the HSCT ozone depletion problem. Worldwide scientific attention is being directed at the effects of man-made pollutants on the Earth's upper atmosphere, with particular attention to protection of the stratospheric ozone layer. As a major U.S. participant in this effort, NASA reports regularly to the Congress and to concerned agencies on the status of upper atmospheric research, and on scientific assessment of potential effects of human activities. These reports now include the Atmospheric Effects of Stratospheric Aircraft (AESA) element of the HSRP.



AESA SCIENTIFIC ADVISORY PANEL

The HSRP places primary emphasis on the understanding and assessment of atmospheric effects. As previously indicated, this research is guided by a committee representative of the international scientific community, and coordinated by leaders of the NASA UARP. Members include Professor Harold Johnston, who first identified the potential problem of ozone depletion by SSTs, other prominent academics, NOAA scientists, and a public interest organization scientist. The FAA and EPA are represented by ex-officio members, and aircraft industry observers participate in committee meetings.

ATMOSPHERIC EFFECTS OF STRATOSPHERIC AIRCRAFT SCIENTIFIC ADVISORY PANEL

<u>Name</u>	<u>Affiliation</u>
Mr. Robert E. Anderson	NASA Headquarters
Dr. R. A. Cox	Natural Environment Research Council, UK
Prof. Frederick L. Dryer	Princeton University
Prof. Dieter H. Ehhalt	Institute for Atmospheric Chemistry, FRG
Prof. James R. Holton	University of Washington
Dr. Harold S. Johnston	University of California, Berkeley
Dr. Nicole Louisnard	Office National d'Etudes et Recherches Aerospatiales, France
Dr. Jerry D. Mahlman	NOAA/Geophysical Fluid Dynamics Laboratory
Dr. Taroh Matsuno	University of Tokyo/Geophysical Institute
Dr. Mario J. Molina	Massachusetts Institute of Technology
Dr. Michael Oppenheimer	Environmental Defense Fund
Dr. Alan Plumb	Massachusetts Institute of Technology
Dr. Michael J. Prather	NASA/Goddard Institute for Space Studies
Dr. A. R. Ravishankara	NOAA/Environmental Research Laboratory
Dr. Adrian Tuck	NOAA/Aeronomy Laboratory
Dr. Robert T. Watson	NASA Headquarters
Dr. Steven C. Wofsy	Harvard University
Dr. Donald J. Wuebbles	Lawrence Livermore National Laboratory

"Stratospheric Models & Measurements: A Critical Comparison"

The Role of HSRP/AESA

Michael J. Prather
NASA/GISS, New York

The High-Speed Research Program of NASA (HSRP) is charged with assessing by 1995 the environmental impact of a projected fleet of high-speed civil transports (HSCTs, a commercial supersonic aircraft fleet). In order to prepare for the assessment of chemical perturbations to the atmosphere from the proposed fleet, HSRP, through the Atmospheric Effect of Stratospheric Aircraft (AESA) studies, has supported basic research in atmospheric modeling, laboratory studies of chemical reactions, and instrument development. A stated intent of HSRP/AESA is to develop and validate the global chemical transport models (CTMs) that are the essential element of the program.

Assessment of the impact of aircraft exhaust (from *projected* supersonic fleets) on stratospheric chemistry, and particularly ozone, will rely on our 2-D and 3-D global atmospheric models. It has been duly noted at several meetings that the community has presented and published numerous model simulations for future scenarios, but that we have no objective (i.e., quasi-standard) criteria for judging which models are "reliable" for today's atmosphere. The extensive "2-D Intercomparison of Stratospheric Models" (September 1988, Virginia Beach, Jackman et al., NASA CP-3042, 608 pp.) went a long way toward documenting the similarities and differences among the available 2-D and 3-D models in terms of both chemistry, radiation and circulation. This model intercomparison was not immediately followed up by another because, for one, the community was exhausted, and moreover, the limitations of a model-model intercomparison had been pushed to the limit.

We are now taking the next significant step of a model-measurement comparison. Dr. Ellis Remsberg (NASA Langley) has consented to chair this effort that will culminate in an international workshop "Stratospheric Models & Measurements: A Critical Comparison" in early 1992. This new workshop will likely include some specific model-model intercomparisons that have not been adequately answered by the 1988 meeting (e.g., photolysis rates), but will focus on a set of measurements and parallel model simulations. The style will be similar to the last comparison, in which one individual (model or

data connections) would take one of the prescribed cases (e.g., total ozone) and cross-compare all model simulations as well as all the different measurements and their uncertainties. We will rely on the UADP database (Dr. Robert Seals, NASA Langley) as the repository for all observational data and model simulations, and as the source of the comparisons (graphic or tabular).

This effort is being organized by a core of researchers, primarily those involved in data analysis and includes only some representatives from the modeling community. This summer we will reach out to the remaining groups involved in HSCT assessments for HSRP/AESA or in CFC-related ozone assessments for the Montreal Protocol re-evaluation. This effort is an important new initiative in our community, and the responses from researchers in both modeling and measurements have been encouraging and even enthusiastic. My charge to this committee is

- (1) to establish a standard set of atmospheric measurements that can be used to test the reliability of atmospheric chemistry models,
- (2) to develop a method for evaluating model-data comparisons,
- (3) to direct the first major international stratospheric model-data comparison.

CALENDAR

March 13-14, 1991 (DC area)

First committee meeting, define types of datasets and model runs.

May 15-16, 1991 (Williamsburg, VA)

Make final decisions on datasets and model simulations.

June-July 1991

Circulate letter with final definitions for Feb comparison.

Dec 1991

Models and Measurements must have data to Bob Seals.

Feb 1992

International workshop: stratospheric model-measurement comparison.
A small group, no more than 32 participants.

HSRP / Atmospheric Effects of Stratospheric Aircraft
Earth Science and Applications Division (OSSA/SE)

HSRP/AESA Program Objective:

Prepare for a 1995 Scientific
Assessment of the Atmospheric
Impact of a Projected Fleet of High-
Speed Civil Transport Aircraft.

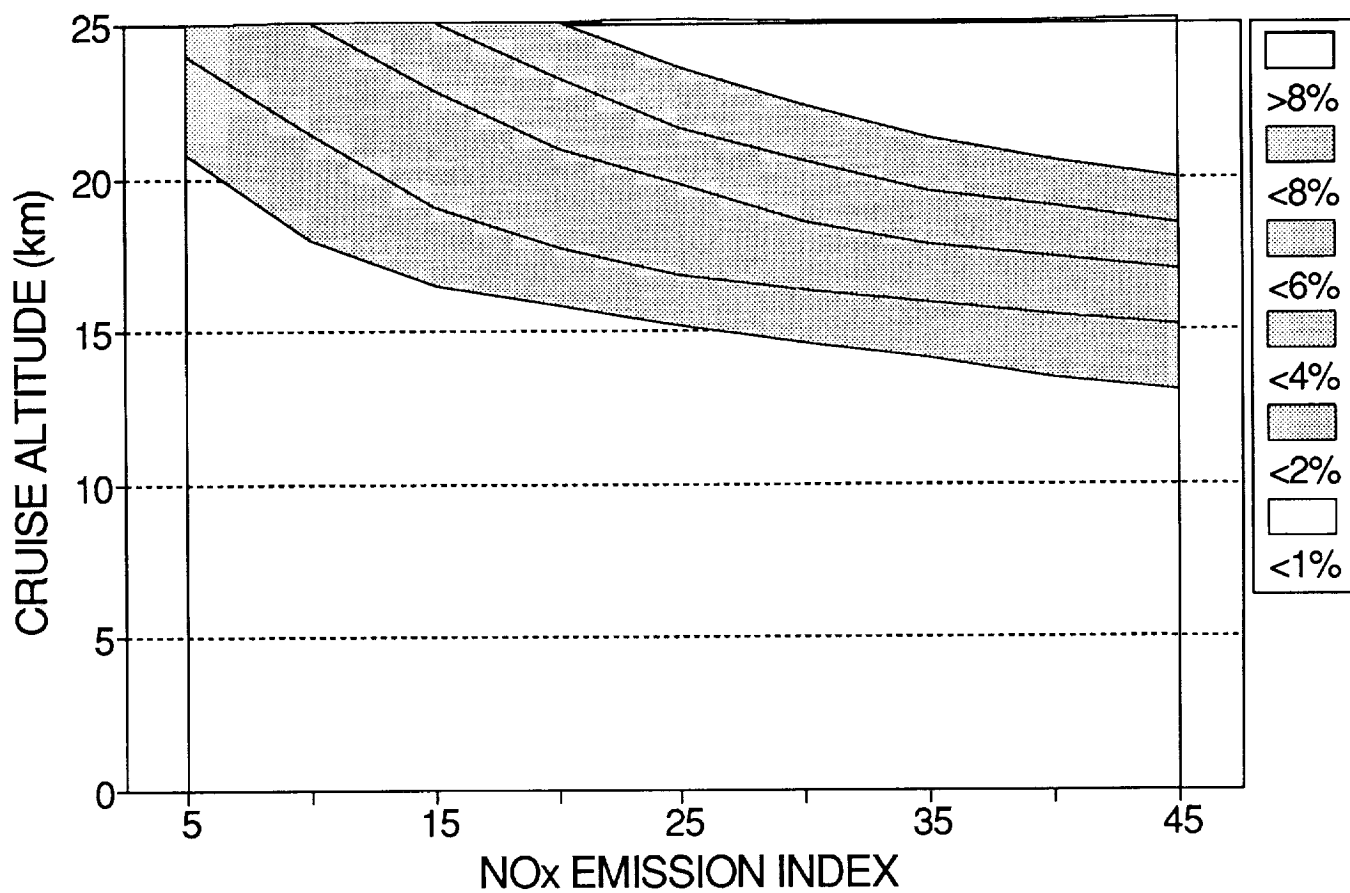
HSRP/AESA: What is the Problem?

HSCT Emissions (Mach 2.4):

<i>species</i>	<i>perturb. / natural background</i>	
CO ₂	1 ppm / 350 ppm	
H ₂ O	1 ppm / 4 ppm	==> OH, HO ₂ , climate
NO _y (NO ₂)	4 ppb / 16 ppb	==> NO ₂ +O → NO+O ₂
CO	1.5 ppb / 10 ppb	
hydrocarbons		
SO ₂		==> aerosol chemistry,
soot		radiation

MEAN COLUMN OZONE DEPLETION (%)

(ref: Jackman et al, GSFC, 1991)



HSRP/AESA Components:

Scenarios for Aircraft Fleet Emissions

- 1. Engine Exhaust**
- 2. Fleet Scenario**

Predictive Global Models:

- 1. Accumulation & Dispersion of Exhaust**
- 2. Resulting Chemical Perturbation**

Laboratory Studies of Chemical Mechanisms

Current Atmospheric Measurements

Identify Weaknesses, Quantify Uncertainty

HSRP/AESA ACCOMPLISHMENTS

- 1988 Forge OAET/RJ - OSSA/SE Link
 Form Advisory Panel, Design AESA Studies

- 1989 First NRA (joint R & E), Research Funding

- 1990 Ad Hoc Committee on Emissions
 Ames Workshop on Atmospheric Measurements
 "White Papers" on HSCT (NASA Ref.Publ.)
 Second NRA & Research Funding

- 1991 First Annual Meeting - Va Beach
 Committee on Models & Measurements
 Committee on Aircraft Campaigns
 Committee on Aerosols, Soot & Particulates



NATIONAL AERONAUTICS
AND SPACE ADMINISTRATION

August 15, 1990

NRA-90-OSSA-20

Research Announcement

The Atmospheric Effects of Stratospheric Aircraft: Modeling and Measurement in Support of the High-Speed Research Program

NASA Research Announcement

THE ATMOSPHERIC EFFECTS OF STRATOSPHERIC AIRCRAFT: MODELING AND MEASUREMENT IN SUPPORT OF THE HIGH-SPEED RESEARCH PROGRAM

NASA Research Announcement NRA-89-OSSA-16

Released July 1989, Proposals due 31 Oct 89

25 / 42 Proposals accepted

NASA Research Announcement NRA-90-OSSA-20

Aug 1990, Proposals due 1 Nov 90 & 1 May 91

About 35 proposals in each cycle

Research Elements of HSRP/AESA Studies:

Engine/Airfleet Emission Scenarios

Aircraft Plume Chemistry and Dispersion

Global Transport and Accumulation of Aircraft Exhaust

Global Chemical Models for Stratospheric Ozone

Aircraft Impacts on Tropospheric Chemistry and Climate

Lab Measurements of Gas and Aerosol Chemistry

Atmospheric Observations and Field Experiments

**NASA
Reference
Publication
1250**

1991

**The Atmospheric Effects
of Stratospheric Aircraft:
A Topical Review**

H. S. Johnston
*University of California
Berkeley, California*

M. J. Prather and R. T. Watson
*NASA Office of Space Science and Applications
Washington, D.C.*

NASA
National Aeronautics and
Space Administration
Office of Management
Scientific and Technical
Information Division

1991

The Atmospheric Effects of Stratospheric Aircraft: A Current Consensus

A. R. Douglass
Goddard Space Flight Center
Greenbelt, Maryland

M. A. Carroll
NOAA Aeronomy Laboratory
Boulder, Colorado

W. B. DeMore
Jet Propulsion Laboratory
Pasadena, California

J. R. Holton
University of Washington
Seattle, Washington

I. S. A. Isaksen
Institute of Geophysics
Oslo, Norway

H. S. Johnston
University of California
Berkeley, California

M. K. W. Ko
Atmospheric Environmental Research, Inc.
Cambridge, Massachusetts

HSRP/AESA First Program Report

The Atmospheric Effects of Stratospheric Aircraft: A First Annual Report (NASA Ref. Publ.)

Chapter 0. Introduction (Prather & Wesoky)

Chapter 1. Aircraft and Engine Emissions (Miake-Lye)

Chapter 2. Natural Cycles: Gases (Douglass)

Natural Cycles: Aerosols (Turco)

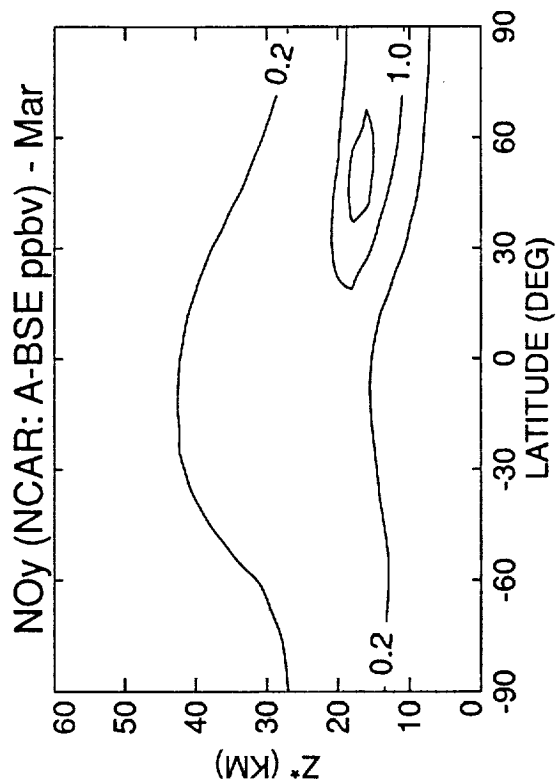
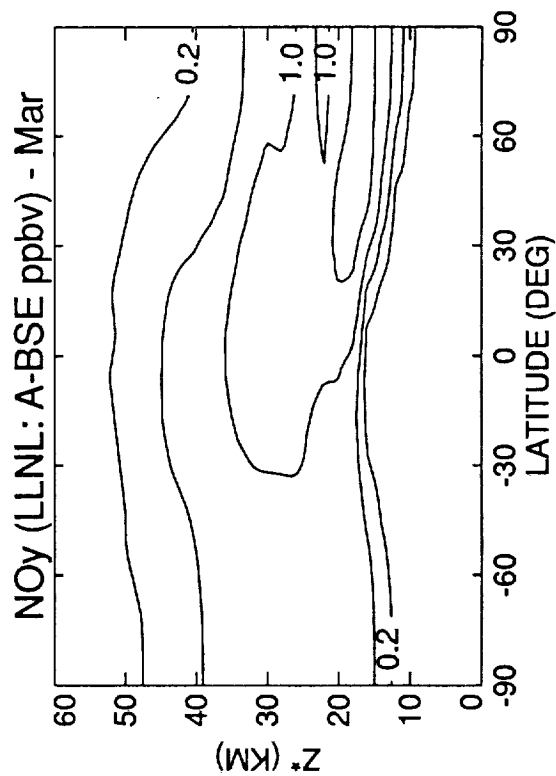
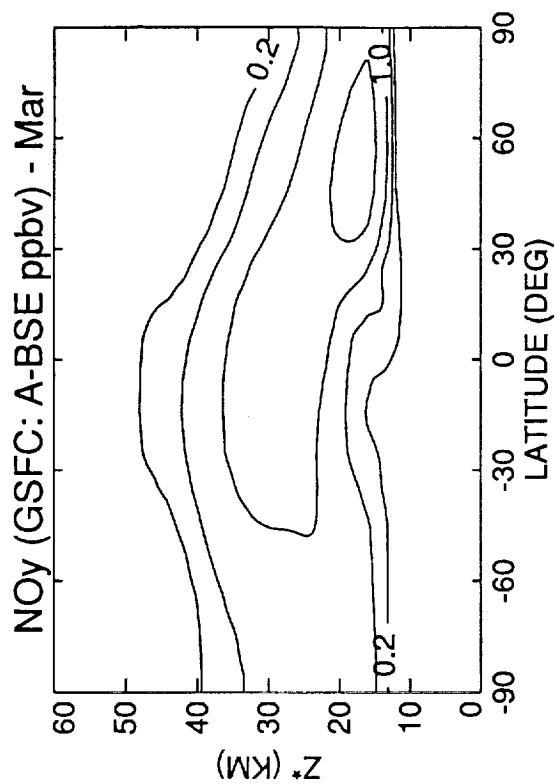
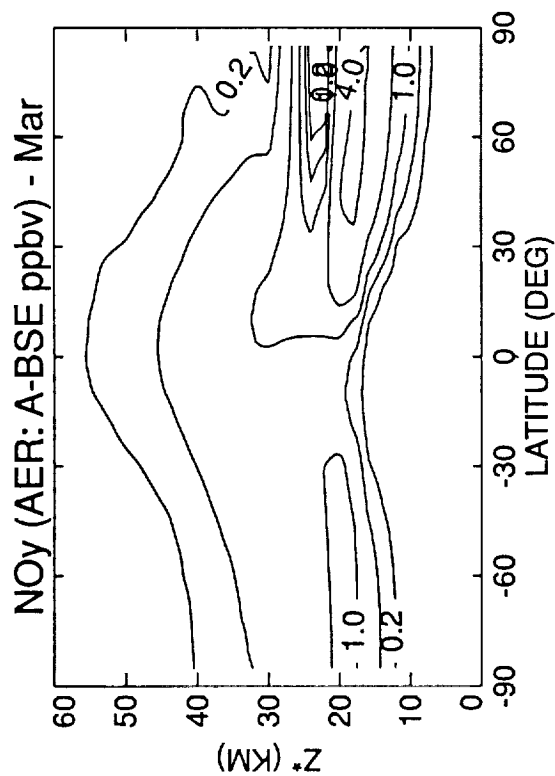
Chapter 3. Scenarios for Future Air Travel (Wuebbles)

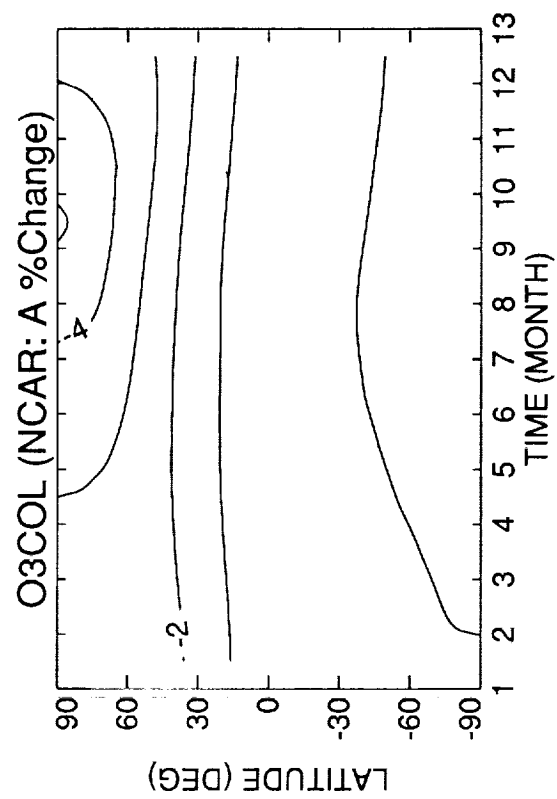
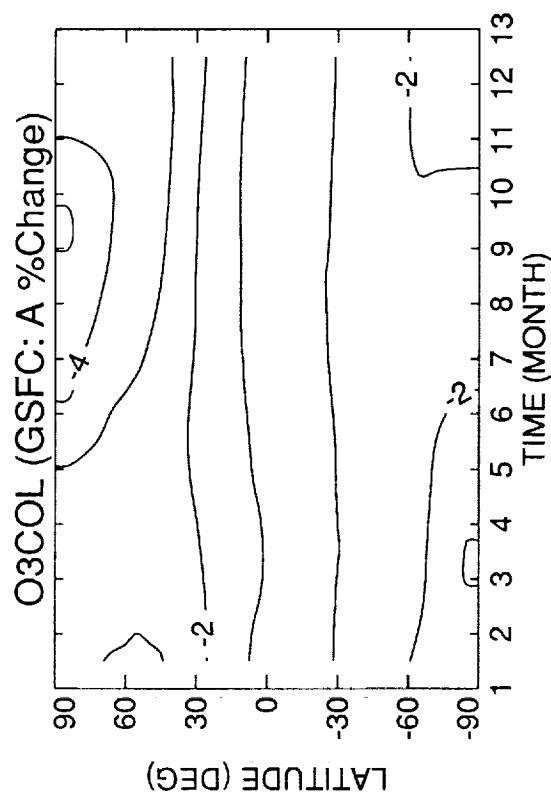
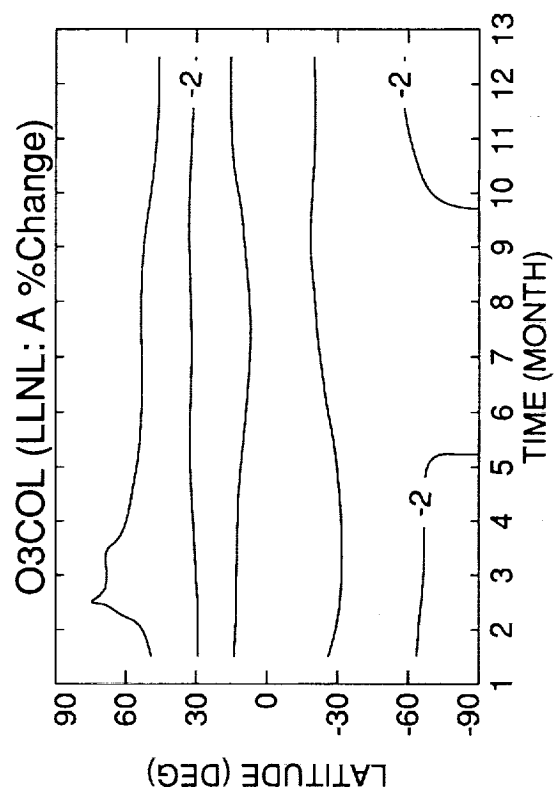
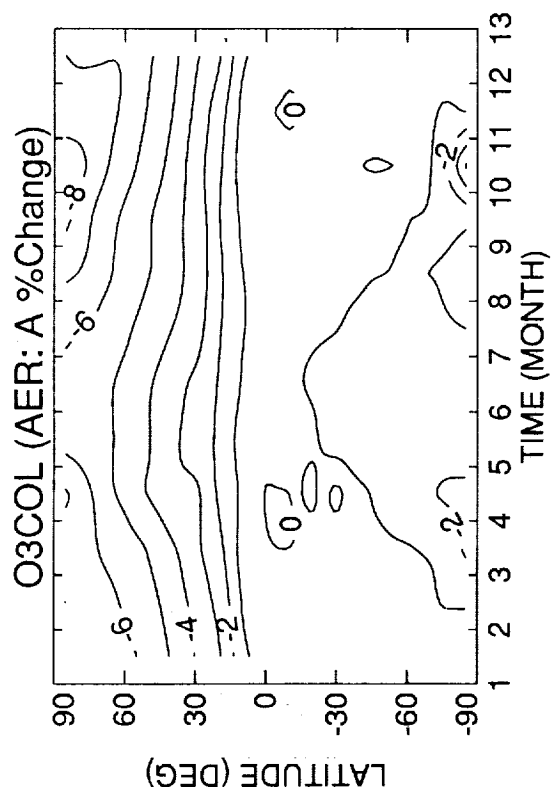
Chapter 4. Sensitivity Studies with 2-D models (Ko)

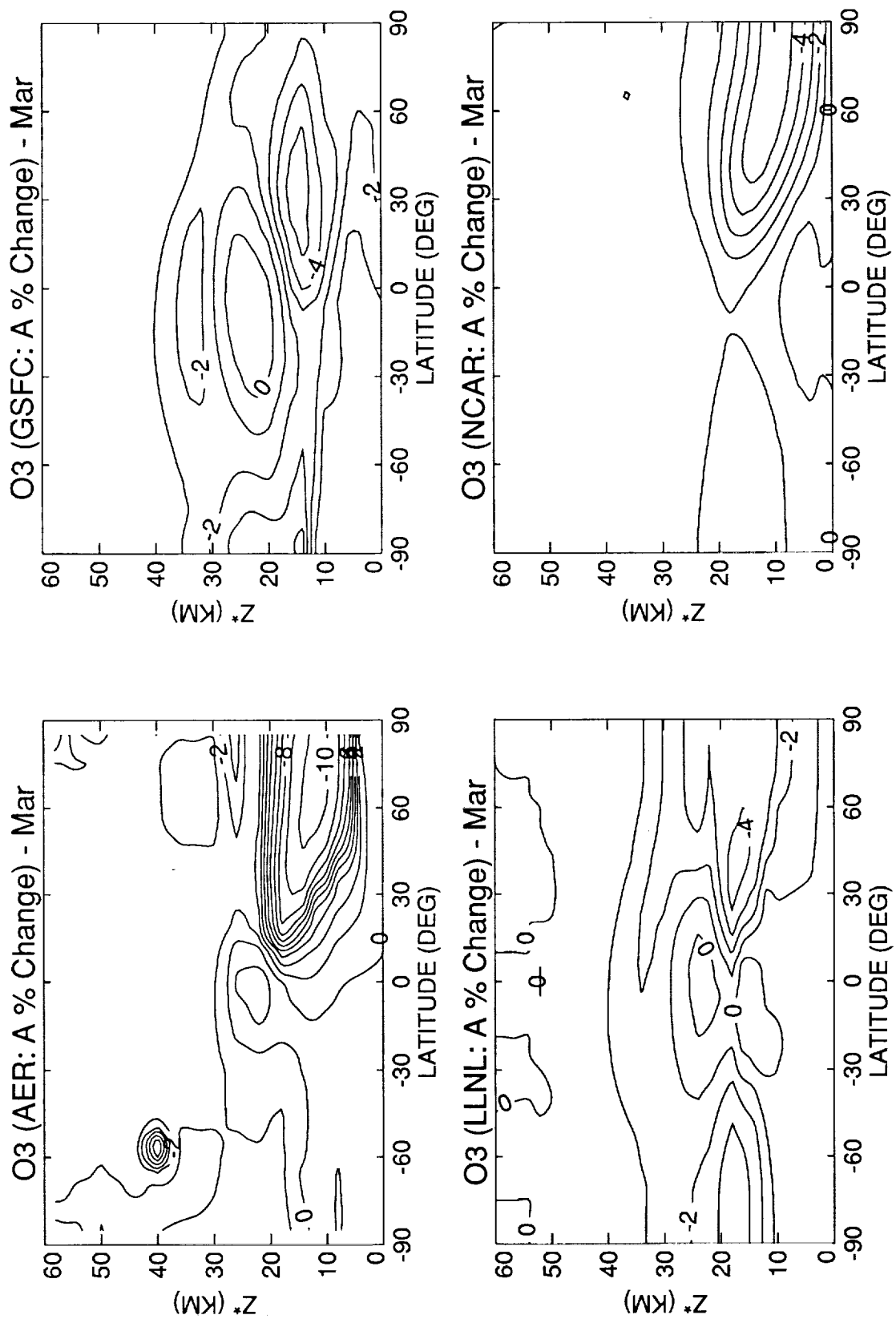
Chapter 5. Aircraft Campaign Workshop (Schmeltekopf)

Chapter 6. HSRP/AESA Research Abstracts (PI's)

(External Review Complete)



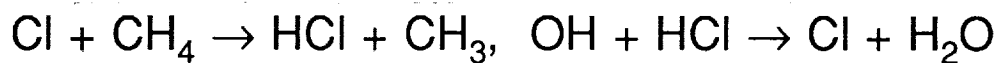
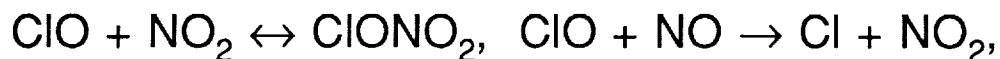




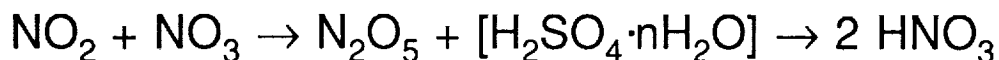
HSRP/AESA: Complications?

Stratospheric Ozone Chemistry

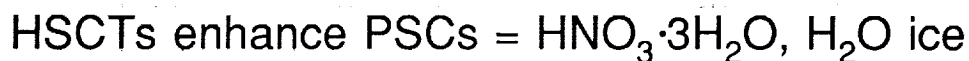
Chlorine - Nitrogen Interference: ClO destroys O₃



Heterogeneous Chemistry [sulfate]: NO₂ destroys O₃



Polar Stratospheric Clouds: HCl & ClONO₂ → ClO



HSRP/AESA PLANS & MILESTONES

- 1991 First Annual Report
 AASE-II Measurement Campaign

- 1992 Models & Measurements Comparison
 SPADE-I Measurement Campaign
 UNEP-WMO Report on Ozone & CFCs

- 1993 Annual Meeting / NAS Review
 UARP Report to Congress on Ozone

- 1994 SPADE-II Measurement Campaign

- 1995 Annual Meeting / International Review
 Report to UNEP-WMO on Ozone

HSRP/AESA Aircraft Campaigns

AASE-II: Second Airborne Arctic Stratosphere Expedition

October 1991 thru March 1992, ER-2 & DC-8 platforms

Primary: Upper Atmos Research Program / OSSA

HSRP additional support for specific objectives:

- Extend chemical tracer observations (latitude & altitude)

- Examine NO_x & O₃ chemistry as strat-troposphere mix

- Identify possible signature of subsonics in stratosphere

- Opportunity to sample Concorde flight corridor

SPADE: Stratospheric Photochemistry, Aerosols & Dynamics Expedition

September 1992, ER-2 (from Ames) & Balloons (Dryden)

New instruments - NO/NO_y, CO₂, OH/HO₂

Diurnal chemistry - OH, HO₂, NO, NO₂, ClO, BrO

Heterogeneous chemistry on sulfate aerosols

NO_x chemistry in lower stratosphere

A campaign directed at the needs of the High-Speed Research Program

Stratospheric Photochemistry, Aerosols & Dynamics Expedition: SPADE '92

ER-2, September 1992 (4 weeks) out of Ames (Moffett Field)

Radicals & Fast Chemistry:

NO, NO₂, HNO₃, HCl, ClO, BrO, OH, HO₂, O₃.

Reservoirs & Tracers:

NO_y, H₂O, CH₄, N₂O, CFCI₃, CO₂.

Aerosols & Dynamical Variables:

Aerosol surface, CN, T, pv, winds, clouds

UV-Visible irradiance, in situ and satellite observations

Flights: 12 6-hr flights out of Moffett (MWF for 4 weeks)

Sunrise Diurnal (2) and Sunset Diurnal (2)

Mid-Day with dives for profiling (2)

Latitude to 19 N & dive (1), to 55 N & dive (1)

Reserve (3) and Engineering (1)

Balloons, September 1992 (same period) out of Dryden (Edwards AFB)

Light-Weight Packages, if available: NO, NO_y, N₂O, ClO, O₃.

Flights: 2, if possible, to coincide with ER-2 overpasses.

Meteorological Support

Real-time Forecasts and Satellite Imagery

Trajectories and other Dynamical Analyses

Data Analysis and Photochemical Modelling (in field)

Project Scientist:

Steve Wofsy

Deputy Project Scientist:

Art Schmeltekopf

Project Manager:

Estelle Condon

Program Scientist:

Michael Prather

HSRP Program-Wide Issues Linked with Assessment:

Assess Realistic Fleet Emission Scenarios based on the best Engine Emissions, Aircraft Efficiency, Operational Constraints.

Coordinate Scientific Assessment with Optimization of Airframe/Engine Design.

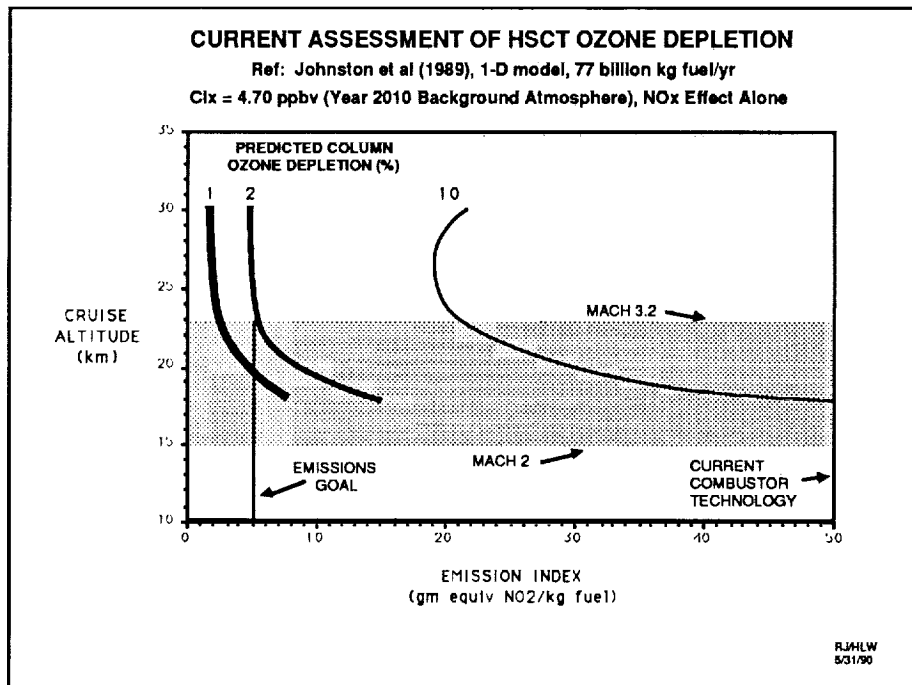
Coordinate Scientific Assessment with National & International Regulatory Agencies.

Define Uncertainties in the Assessment:

- Gas and Aerosol Chemistry
- Future Atmospheric Composition & Climate
- Validation of Global Models

CURRENT ASSESSMENT OF HSCT OZONE DEPLETION

Although continuing atmospheric studies, as typified by this current 1-D model assessment, are needed to fully understand and quantify the levels of NO_x emissions that may be acceptable, it is clear that combustion technology development focussed on reducing NO_x is paramount before U.S. industry could commit to an HSCT development program. Fortunately, prior programs such as those sponsored by NASA and the Department of Energy (i.e., for stationary gas-turbine powerplants) indicate that reduction to levels in the range of 3 to 8 grams of NO_x per kilogram of fuel is possible with advanced combustor design concepts.



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HSR EMISSIONS TECHNOLOGY

STATUS REPORT

1ST ANNUAL HIGH-SPEED WORKSHOP

MAY 14, 1991

**JOHN R. FACEY
ACTING DEPUTY DIRECTOR
PROPULSION, POWER & ENERGY DIVISION
OFFICE OF AERONAUTICS, EXPLORATION AND TECHNOLOGY**

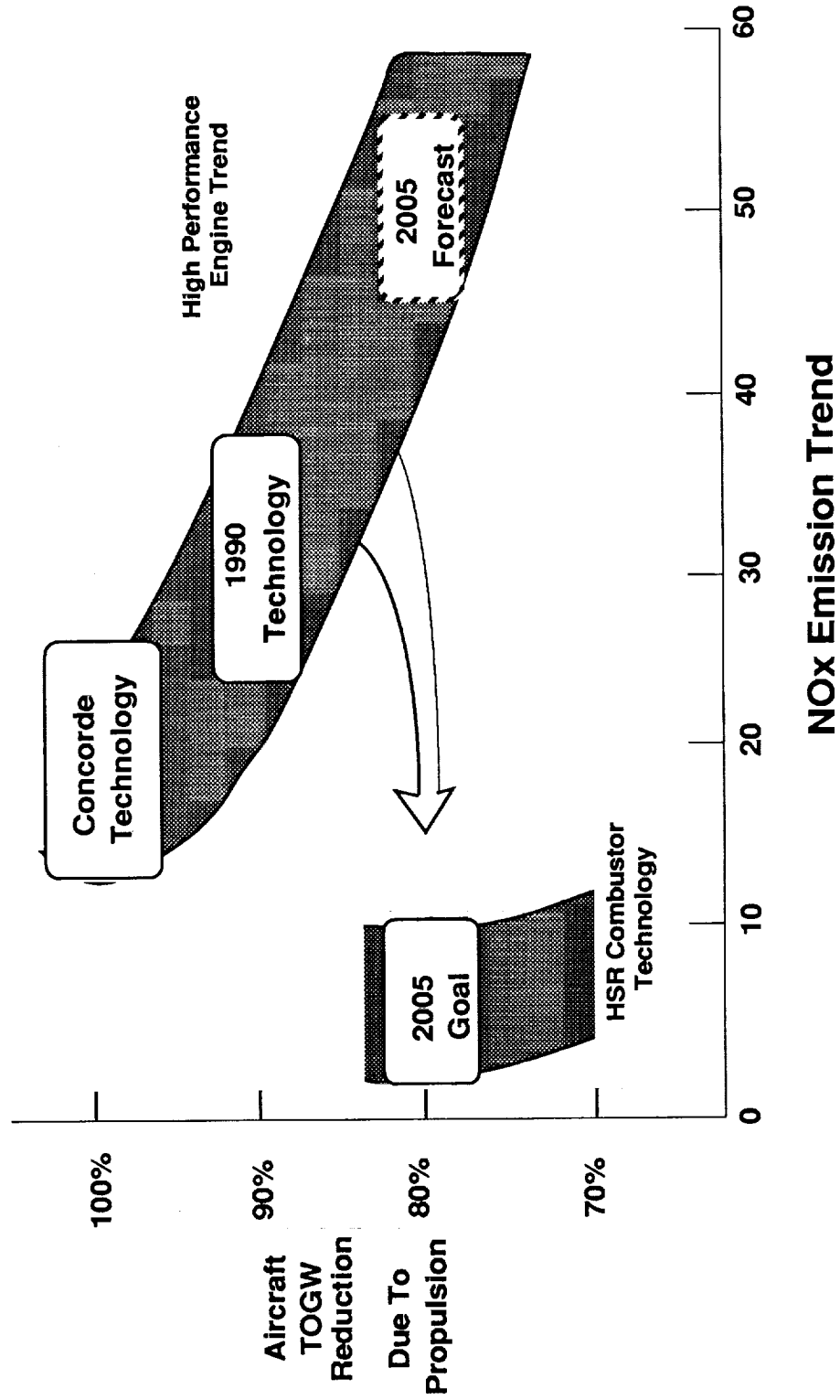
STATE OF TECHNOLOGY - COMBUSTOR EMISSIONS

The current aircraft production state-of-the-art for establishing High-Speed Civil Transport emissions is based on the technology demonstrated by the Concorde propulsion system. Unfortunately, the requirement for an economically viable high-speed transport will result in an advanced propulsion system that produces increased NOx emissions if it uses current combustion technology. The engine and flight parameters that will cause increased levels of NOx for a system designed for introduction in 2005 versus the Concorde are:

- Increased flight Mach number which results in increased propulsion system temperatures and pressures, in particular, the for the combustor
- Increased engine cycle pressure ratio which will also raise the combustor inlet temperatures and pressures
- Increased engine cycle (combustor exit) temperatures

It is forecast that a economically viable 2005 engine that uses current technology for combustor design will result in a NOx emissions index that is nearly three times as high as the Concorde. Thus it is necessary to develop advanced technology for application in new combustor concepts to attain the goals of the HSR program.

State of Technology - Combustor Emissions



ULTRALOW NO_x COMBUSTOR DESIGN CONCEPTS

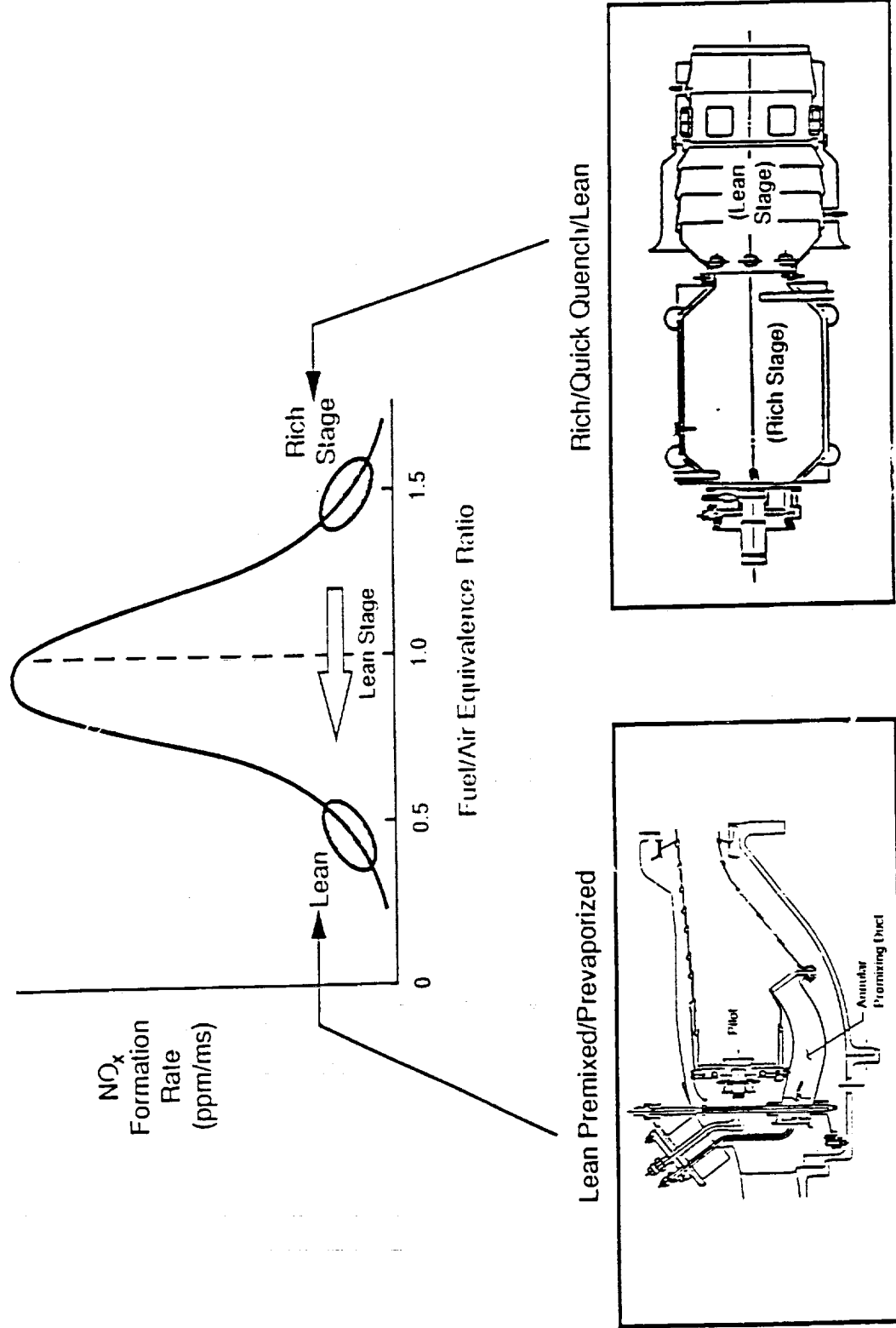
The amount of NO_x produced by a gas turbine combustor is a function of a number of parameters in the combustion process:

- Increased maximum temperature in combustion zone yields more NO_x
- Increased combustor inlet temperature yields higher NO_x
- Longer residence time at maximum gas temperature yields more NO_x
- Higher combustor pressure level yields more NO_x (relatively weak function)

Compared to current operational combustors, the HSR combustor will operate at increased inlet and exit temperatures as well as higher pressures. Thus the only parameters available to us for control of the production of NO_x are the maximum temperature in the combustion zone and the residence time at the maximum temperature. The combustion zone temperature is controlled by operating at the minimum fuel/air equivalence ratio (lean) required to attain the desired turbine inlet temperature. While simple in concept, practical application of the lean approach to a combustor may be difficult because of the problem of attaining uniform fuel/air mixing without undesirable effects such as flashback. Thus, a second concept is being considered that uses a rich burn portion of the combustor, which reduces the need for perfect mixing of the raw fuel with the air, to convert the fuel into gaseous products followed by a rapid mixing of the combustion gases and the remaining combustion air prior to completing the combustion process at the same lean equivalence ratio as the lean burn concept. Each of these concepts are intended to maintain the maximum temperature below the level that results in rapid NO_x formation.

Each of these concepts must also be implemented so that that highest temperature is maintained for very short periods. Thus, they must be as short in length as possible.

Ultralow NO_x Combustor Design Concepts



EMISSIONS PROGRAM KEY MILESTONES

The approach to emissions reduction technology development couples analytical and experimental efforts in a process that first builds a strong fundamental foundation, and then applies that knowledge base to engine-level combustor hardware for rig verification tests:

- Early in the program analysis codes are being used to assess proposed concepts and configurations to identify and support laboratory-level experiments. Advancements in detailed computational analysis are providing increasingly better insight to complex flow processes at the controlling physics level. The experimental testing, including rapid fuel vaporization and fuel-air mixing, rich- and lean-fuel combustion chemical kinetics, flashback criteria and avoidance, is defining key design factors that must be achieved at both the subcomponent and full combustor hardware level. NOx destruction additives were to be a part of the experimental program, but, to date, no additives studied analytically have resulted in a significant reduction in NOx under lean conditions with acceptable residence times and/or environment impact. If a good additive is discovered, it will be tested at a later date.
- Development of low-emission combustor technology will then proceed in a building block manner beginning with key subcomponents such as the fuel injector and fuel-air mixing devices. Once all subcomponent requirements are individually achieved, they will be integrated into practical sector and full combustor designs in a series of development tests over the complete range of simulated operating conditions.

Significant university and U.S. industry participation with the NASA research centers is an integral part of this approach to insure all available expertise and facilities are applied in solving this difficult and critical challenge.

EMISSIONS PROGRAM KEY MILESTONES

FY 1991	FLAMETUBE TESTING OF BOTH LEAN/PRE-MIXED/ PREVAPORIZED & RICH-BURN/QUICK-QUENCH/ LEAN-BURN CONCEPTS
FY 1992	LABORATORY COMBUSTION DATA BASE COMPLETED
FY 1993	CODE UPDATE BASED ON LABORATORY DATA BASE AND SUB-COMPONENT TECHNOLOGY DATA BASE
FY 1994	INITIATE COMBUSTOR RIG TESTING
FY 1995	VERIFICATION OF 3-8 EMISSIONS INDEX IN PRACTICAL COMBUSTOR CONFIGURATION

HSR SQUARE FLAME TUBE RIG LEAN PREMIXED/PREVAPOORIZED COMBUSTION (LPP)

The laboratory environment for controlled research and concept technology development using advanced diagnostics is provided by the Lewis Research Center's flame tube facility. It provides a

- wide-range of preconditioned inlet air temperature, pressure, and humidity
- high-accuracy measurement of fuel and airflow rates
- fuel droplet size; laser velocimetry; Schlieren photography; and laser induced fluorescence measurements; and
- combustion products gas sampling probes at three axial locations.

A "parallel - dual leg" capability provides flexibility and concurrent testing of alternate concept configurations. A lean premixed prevaporized configuration has been evaluated during the last year, and a rich-burn / quick-quench / lean-burn configuration has now been installed in the second leg of the facility.

HSR SQUARE FLAME TUBE RIG LEAN PREMIXED/PREVAPORIZED COMBUSTION (LPP)



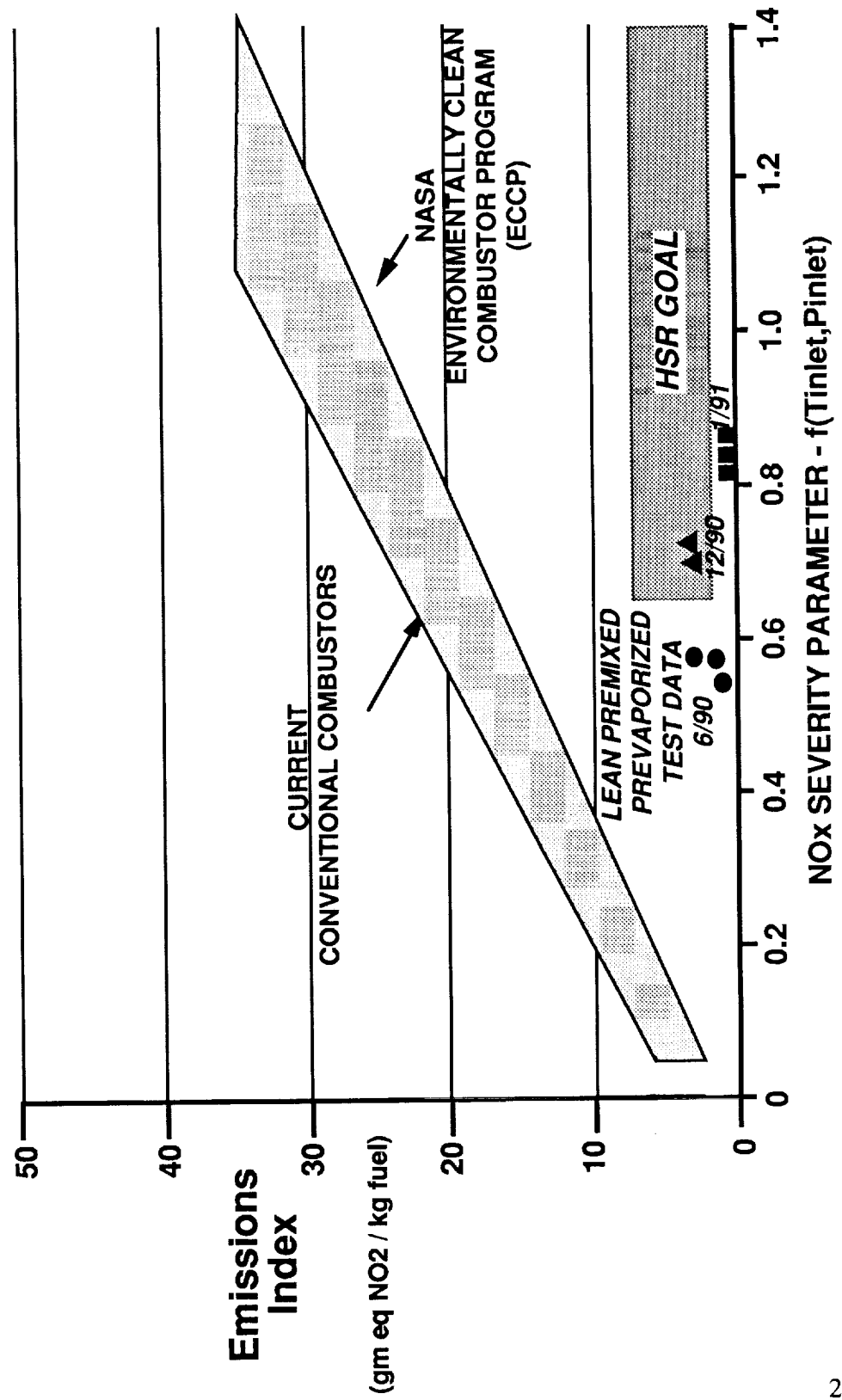
LEAN PREMIXED PREVAPORIZED (LPP) FLAMETUBE RESULTS

Emission indices better than the HSRP goal level of 5 grams equivalent NO_2 /kilogram fuel have been demonstrated in the Lewis flametube facility, and are very encouraging relative to the predicted ozone depletions presented earlier. Very good results have been obtained with plain jet injectors at lower severity factors and with multiple venturi injectors at higher severity factors. The most recent LPP results were obtained at a severity factor near 1.0 with emission indices remaining below 3g/kg. The rich-burn/quick-quench/lean-burn flame tube rig has been checked out at cold flow conditions and LeRC is expected to begin burning tests this week. NASA expects to have completed the flame tube experiments by the end of FY 1991 that will establish the technology capability and critical factors for achieving a 3-8 emissions index at simulated supersonic cruise conditions.

These early results are nearly an order of magnitude below current stoichiometric primary-zone combustors used in modern high-bypass engines. However, considerable effort will be required to integrate the laboratory concept into a practical engine configuration. Planned additional testing will include extensive mapping of the severe HSRP goal environment and development of a sensitivity database (e.g., fuel-air mixing) for code validation and updating prior to the selection of combustor concepts at the end of FY 1992 for development of a combustor rig for validation of the HSR emission goals in FY 1995.

HIGH-SPEED RESEARCH PROGRAM EMISSIONS REDUCTION

LEAN PREMIXED PREVAPORIZED FLAMETUBE RESULTS



EMISSIONS STANDARDS

Emissions standards will be critical to the development of HSCT aircraft, but currently exist for no aircraft at cruise altitudes. The regulatory process will probably be based on existing EPA authority under the Clean Air Act, and involve broad government and industry cooperation in preparing an environmental impact statement. By 1993, HSRP progress should serve as a basis for a national assessment of potential HSCT atmospheric impact. Because of the global implications of atmospheric pollution, it is expected that the U.N.'s International Civil Aviation Organization (ICAO), through its Committee on Aviation Environmental Protection, will play a major role in establishing standards.

EMISSIONS STANDARDS

- **ATMOSPHERIC IMPACT OF HSCT FLEET CURRENTLY UNCERTAIN, BUT ASSESSMENT UNDERWAY**
 - CHEMISTRY & DYNAMICS MODELS
 - MEASUREMENTS TO CALIBRATE & TEST MODELS
 - GLOBAL CHANGE ISSUES
- **EMISSIONS STANDARDS DEFINITION CRITICAL TO HSCT PROGRESS**
- **REGULATORY PROCESS FOR CRUISE EMISSIONS NOT ESTABLISHED**
 - CLEAN AIR ACT ALLOWS EPA ADMINISTRATOR TO ASSESS IMPACT
 - ENVIRONMENTAL IMPACT STATEMENT INVOLVING EPA, FAA, NASA AND INDUSTRY WILL PROBABLY PRECEDE REGULATION
- **1993 NATIONAL INTERAGENCY ASSESSMENT PROPOSED**
 - AESA ADVISORY PANEL ASSESSMENT IS PRECURSOR
 - CHARTER NOW BEING CONSIDERED
- **1995 INTERNATIONAL ASSESSMENT FINAL PROPOSED HSRP ACTION**
 - POLITICALLY ESSENTIAL FOR HSCT ECONOMIC SUCCESS
 - LIKELY TO INVOLVE INTERNATIONAL CIVIL AVIATION ORGANIZATION

NOISE STANDARDS

The regulatory situation for community noise is somewhat clearer than for emissions. Federal Aviation Regulations Part 36 (FAR 36), Stage 3 provides current noise rules for subsonic aircraft, and is expected to serve as the basis for HSCT constraints. In May 1990, the FAA issued a Notice of Proposed Rulemaking that suggested that FAR 36, Stage 3 be applied to future civil supersonic aircraft. Although NASA and other organizations which commented on this proposal agree with the spirit of the rule, it was suggested that certification procedures should allow for advanced technology such as computer controlled flap and throttle settings. Also, because of the character of noise from proposed HSCT engines, it was suggested by NASA and others that the procedure be more flexible in terms of noise trades between FAR 36 measuring stations. Such trades might result in higher than currently allowed noise on airport grounds, but lower noise in the surrounding community.

It now appears that the FAA, in recognition of the developing status of technology, will delay noise rule making. It also appears that, as for emissions, considerable international coordination will be required for establishment of HSCT noise standards.

NOISE STANDARDS

- **CURRENTLY NO STANDARDS FOR CIVIL SUPERSONIC AIRCRAFT**
- **FAA MAY 1990 NOTICE OF PROPOSED RULEMAKING SUGGESTED SAME FAR 36, STAGE 3 STANDARDS AS FOR SUBSONIC AIRCRAFT**
- **NASA NOV 1990 COMMENTS SIMILAR TO OTHER RESPONSES**
 - NOISE IMPACT ON COMMUNITY SHOULD BE NO GREATER THAN PRODUCED BY SUBSONIC AIRCRAFT CERTIFIED UNDER STAGE 3
 - HSCT CERTIFICATION RULE SHOULD ALLOW ADVANCED FLIGHT PROCEDURES
 - COMPLIANCE DEMONSTRATION SHOULD BE FLEXIBLE IN TERMS OF NOISE TRADES BETWEEN MEASURING STATION
 - RULEMAKING SHOULD INVOLVE INTERNATIONAL COORDINATION
- **FAA NOW LIKELY TO DELAY RULE**

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HSR SOURCE NOISE TECHNOLOGY

STATUS REPORT

1ST ANNUAL HIGH-SPEED WORKSHOP

MAY 14, 1991

**JOHN R. FACEY
ACTING DEPUTY DIRECTOR
PROPULSION, POWER & ENERGY DIVISION
OFFICE OF AERONAUTICS, EXPLORATION AND TECHNOLOGY**

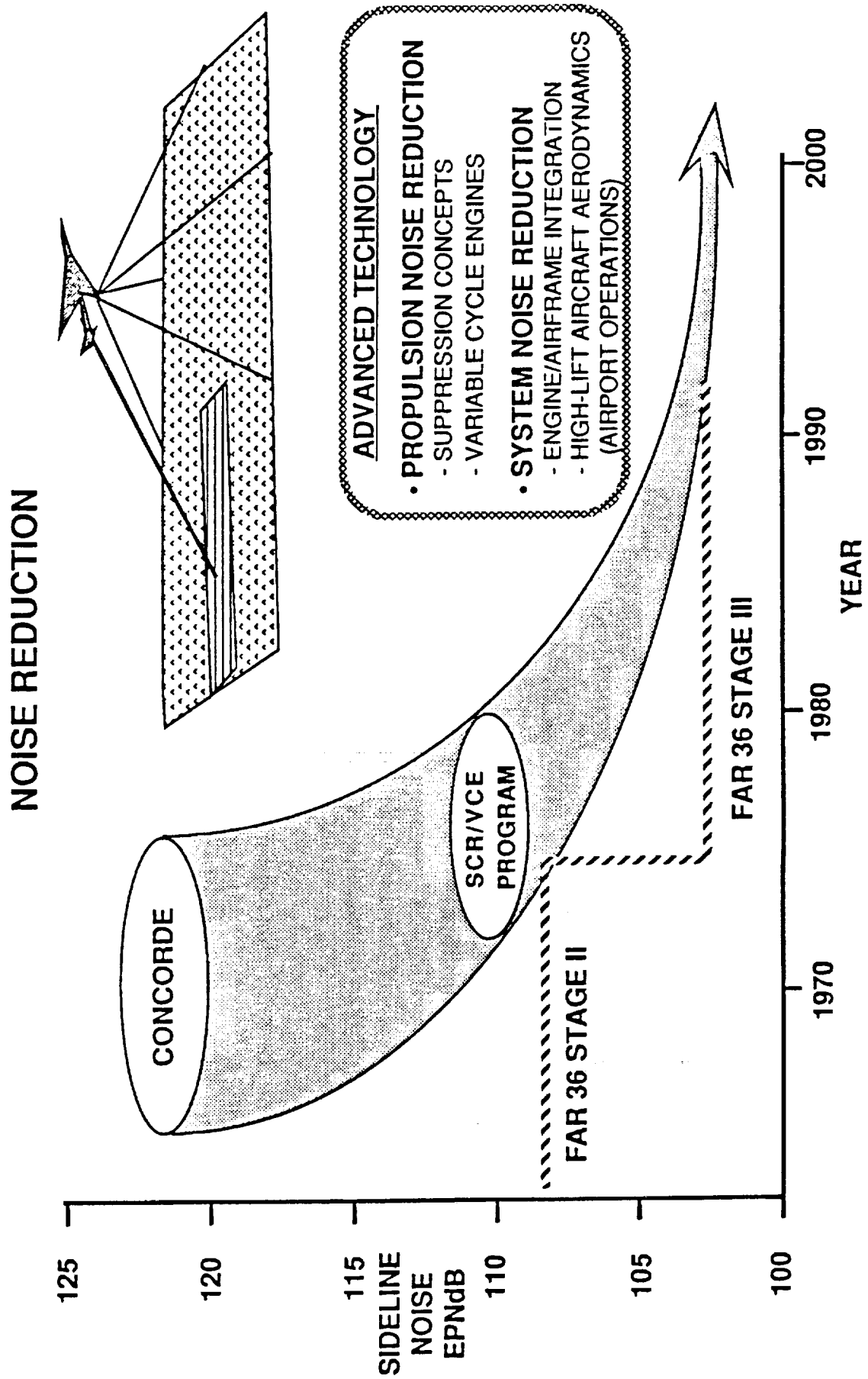
HSCT COMMUNITY NOISE TECHNOLOGY CHALLENGE

Aircraft noise is a subject of significant public concern. This has led to legislation aimed at ensuring noise levels in the airport community meet stringent requirements as set forth in Federal Aviation Regulation, Part 36 (FAR 36). Currently Stage III noise levels are in effect for subsonic aircraft certified after 1975, and have recently been proposed by the FAA as appropriate for supersonic aircraft. The technical challenge is to achieve major jet noise suppression without significant performance and economic penalty.

An estimate of the amount of noise suppression required can be obtained by considering a future commercial transport having a takeoff gross weight of 750,000 lbs., powered by four turbojet engines with 50,000 lbs. thrust. Predicted unsuppressed jet noise for this aircraft at the critical FAR 36 sideline measuring station is 121 EPNdB, which exceeds Stage III requirements by 18.5 dB. Hence, considerable noise reduction is needed to meet this challenge.

To put the challenge in perspective, the SCR/VCE programs of the late 1970's/early 1980's were only able to achieve approximately one half of the required suppression for Stage III compliance. Thus the advanced technology required for noise reduction will need to consider new suppression, advanced cycles, engine/airframe integration and high-lift aircraft aerodynamics technologies.

HIGH-SPEED RESEARCH PROGRAM

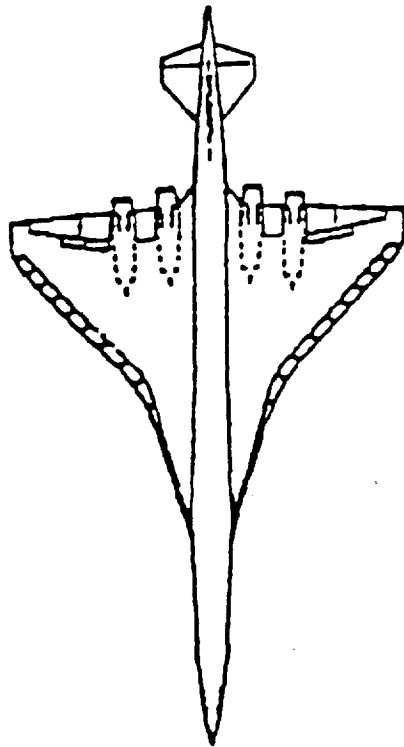


MEETING HSCT COMMUNITY NOISE CHALLENGE A SYSTEM APPROACH

The noise heard by an observer on the ground or received by a microphone measuring station (i.e., such as defined in FAR 36, Stage 3) is a function of the aircraft propulsion source noise levels, the aircraft flight path and the characteristics of the atmosphere. Therefore, in addition to jet noise suppression, advanced aircraft operating procedures may be utilized to achieve low noise levels on the ground. A system approach utilizing all these elements has been defined for the HSRP.

Novel engine concepts with effective noise suppression devices will first be developed to reduce noise at its source. Efficient aerodynamic high-lift concepts will be utilized to reduce takeoff thrust requirements, and hence reduce noise further. Up-rated system noise prediction codes with improved jet noise suppression modules and atmospheric propagation modules will be exercised with advanced aircraft operating procedures to ensure low noise integrated vehicle systems.

HSCT COMMUNITY NOISE TECHNOLOGY Challenge



(4) Engines
TOGW = 750,000 #'s
Net engine thrust T = 50,000 #'s
Engine airflow W = 582 #'s/sec
Engine exhaust velocity $V = T/W$
= 2800 ft/sec

	SIDELINE (1500' SL/1000' Alt)	CUTBACK (1500' Alt)
Predicted jet noise (unsuppressed)	121 EPN dB	118 EPN dB (W=599, T=35000)
FAR 36/Stage 3	102.5 EPN dB	105.3 EPN dB
<u>Required suppression</u>	18.5 EPN dB	12.7 EPN dB

SOURCE NOISE REDUCTION KEY MILESTONES

The approach to source noise reduction technology brings together analytical, fundamental experimental and concept development research efforts in a process that is building a strong fundamental foundation, and applying that knowledge base to advanced concepts for evaluation in scale-model size both without and with forward flight effects before selection of concepts for part-scale verification of performance and noise goals.

- Early in the program a number of advanced concepts are being evaluated both experimentally and analytically while the fundamental experimental data base is being developed. Advanced analytical techniques are being used to guide development and analyze experimental results of advanced concepts such as ejectors designed for maximum secondary air entrainment for noise reduction. The fundamental experiments will be used to help guide the development of improved analytical techniques, verify existing ones, and provide a data base for design of improved noise reduction concepts.
- Facility improvements are also underway. At the Lewis Research Center, the jet exit rig developed for NASP (National Aerospace Plane) nozzle testing has been checked out, and with a new rectangular-to-round transition section that has been recently fabricated, will be used in a number of facilities including the 40x80 wind tunnel at Ames Research Center to evaluate part-scale nozzle concepts for noise reduction. Also, Langley Research Center is in the process of adding forward flight capability to the Jet Noise Lab for fundamental noise experiments.
- As part of the current learning process, a review of progress and needs with the industry resulted in the addition of research for acoustic liners to the HSRP Phase I program as well as a second look at scaling of the model results, especially for suppression liners, and an evaluation of the effects of integration with the airframe on noise suppression.

High levels of university and U. S. industry participation with the NASA research centers is an integral part of the program to ensure maximum use of available expertise and facilities for solving a difficult and critical challenge for high-speed civil transports.

SOURCE NOISE PROGRAM KEY MILESTONES

FY 1991	FUNDAMENTAL ACOUSTIC EXPERIMENTAL DATA BASE AND EARLY CONCEPT ASSESSMENT/SCREENING
FY 1992	COMPLETE SCREENING OF CANDIDATE CONCEPTS AT SCALE-MODEL SIZE INCLUDING FORWARD FLIGHT EFFECTS - INITIAL FAR 36 STAGE III ASSESSMENT
FY 1993	COMPLETE FUNDAMENTAL ACOUSTIC DATA BASE AND UPDATE ANALYTICAL CAPABILITY
FY 1994	DEFINE ENGINE CYCLES/NOZZLES FOR PART-SCALE EXPERIMENTAL EVALUATION
FY 1995	PART-SCALE COMPONENT TESTS, WITH AND WITHOUT FORWARD FLIGHT EFFECTS TO VERIFY PERFORMANCE AND NOISE LEVELS

RAPID MIXING TECHNOLOGY

An example of the fundamental noise reduction research activities at Langley Research Center is an effort to study enhanced mixing of supersonic jets with the surrounding atmosphere and thus lower the emitted noise for a given thrust level. It had previously been demonstrated that rectangular jet exit geometry radiates less noise energy than round nozzles for equivalent thrust. Unfortunately for rectangular configurations it is impossible to separate enhanced mixing introduced by asymmetric flow produced by plume shocks from that introduced by asymmetric turbulent flow structure. However, it has been possible to design a low aspect ratio, $AR=2$, elliptic nozzle that produces shock-free flow for evaluation of asymmetric turbulent flow.

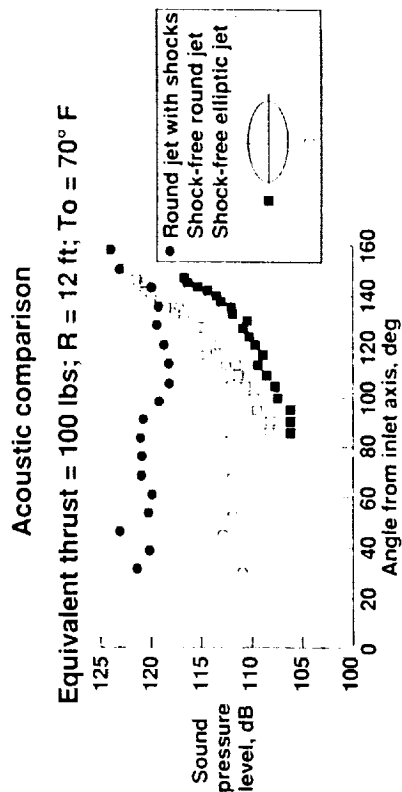
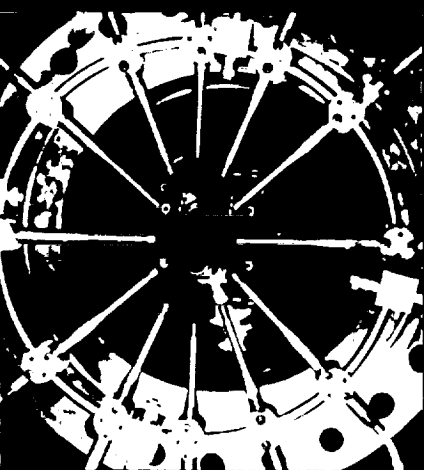
A comparison of round jets with shocks, a shock-free round jet and a shock-free elliptic jet shows that the shock-free round jet produces about 10 dB less noise for sideline at 90° than a round jet with shocks. The elliptic jet produces different levels of noise along the major and minor axes. Compared to shock-containing round jet, the elliptic nozzle provides a sideline reduction of 15 dB at 90° and 5 dB at 140° for the major axis. The results for the minor axis show a minor improvement of 3 dB relative to the shock-free nozzle at 90° . Along the major axis there is a large growth in the momentum thickness due to enhanced vortex entrainment resulting in significant the noise reduction.

For the future, fundamental noise research is continuing with the development of a tri-axial elliptic nozzle test bed and the development of the associated theoretical analysis. Other fundamental jet noise experiments include the study of supersonic instability waves, hot generic nozzles, mixed dual flow nozzles, and single flow plug nozzles with and without porosity.

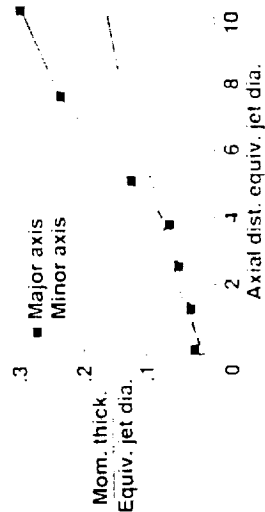
RAPID MIXING TECHNOLOGY AND THE SUPERSONIC ELLIPTIC NOZZLE

Part I: Noise reduction

Mach 1.5 elliptic nozzle



Momentum thickness growth



MIXER/EJECTOR NOZZLES

A number of mixer/ejector nozzle concepts have been designed and experimentally evaluated since the initiation of the HSRP program in 1989. The first was a Boeing concept, a 1970s-era naturally aspirated co-annular (NACA) nozzle modified to achieve enhanced ejector pumping by small high-pressure turbine bypass air tubes placed in the ejector airstream. The concept also used an inverted velocity profile (IVP) with the simulated hot engine exhaust gases fed to the outer stream and the cold ejector air fed to the inner stream. The overall configuration objective was to use the ejector to increase engine airflow while producing a lower mixed jet velocity, and hence lower noise. An experimental evaluation of the NACA nozzle was conducted jointly by Boeing and Langley in the summer of 1989 at the Boeing Low Speed Aeroacoustic Facility. While a noise reduction of 10 EPNdB was achieved relative to round convergent nozzles of similar thrust, the NACA nozzle results were still 10 EPNdB above FAR 36, Stage III requirements.

Although the Stage III goal was not met by the NACA nozzle, it showed that nozzle concepts which augment and mix the engine exhaust with ambient air hold promise for meeting noise goals by providing increased airflow and decreased jet velocity.

New mixer/ejector nozzle concepts, as proposed by Pratt & Whitney (shown) and Boeing, have resulted in increased noise reduction, and have demonstrated secondary ejector flows 120 percent of the primary propulsion system flow, a condition necessary to achieve the desired noise goal.



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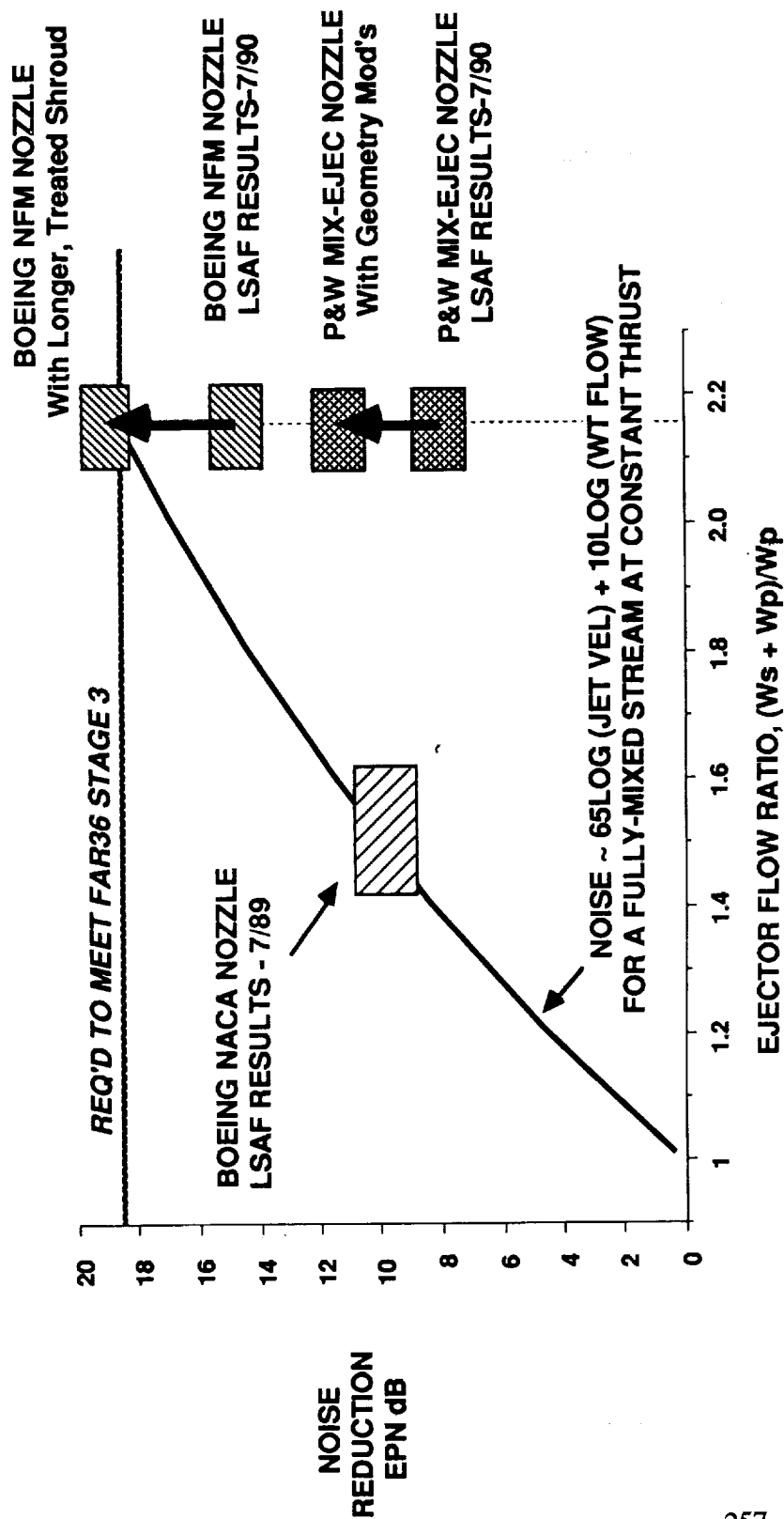
PROMISE OF MIXER/EJECTOR FOR MEETING FAR 36, STAGE III GOAL

Mixer/ejector nozzle concepts are of high interest as a low noise concept because noise is a much weaker function of exhaust weight flow (i.e., 10 log weight flow) than jet velocity (i.e., 65 log jet velocity), thus achieving the desired thrust by higher weight flow rather than high jet velocity which results in a considerable noise benefit.

Both the Pratt & Whitney and Boeing mixer/ejector nozzle concepts have resulted in increased noise reduction at demonstrated high secondary ejector flows (Ws), 120 percent of the primary propulsion system flow (Wp), a condition necessary to achieve the desired noise goal. Continued efforts are still required to enhance mixing of the primary engine exhaust with the ejector flow for improved noise reduction since the particular configuration that achieved the objective noise level utilized a very long, acoustically treated ejector shroud that reduced nozzle performance more than desired. The results to date do, however, show considerable promise that a combination of improved mixing with acoustic treatment could yield a nozzle configuration with the desired level of aerodynamic performance and noise reduction.

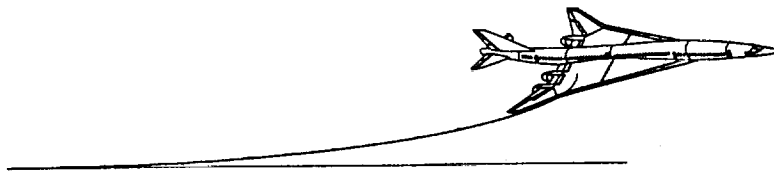
The next series of source noise reduction tests will be conducted this summer in a Lewis wind tunnel with Pratt & Whitney nozzles which will include a see-through window for internal flow diagnostic studies. Other industry concepts include the General Electric 2D suppressor/ejector and the fluid shield nozzle concepts for high flow engine cycles which will be tested in the General Electric acoustic facility starting in mid-1991.

MIXER-EJECTOR NOZZLE DEVELOPMENT PROGRESS



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HSR COMMUNITY NOISE REDUCTION TECHNOLOGY



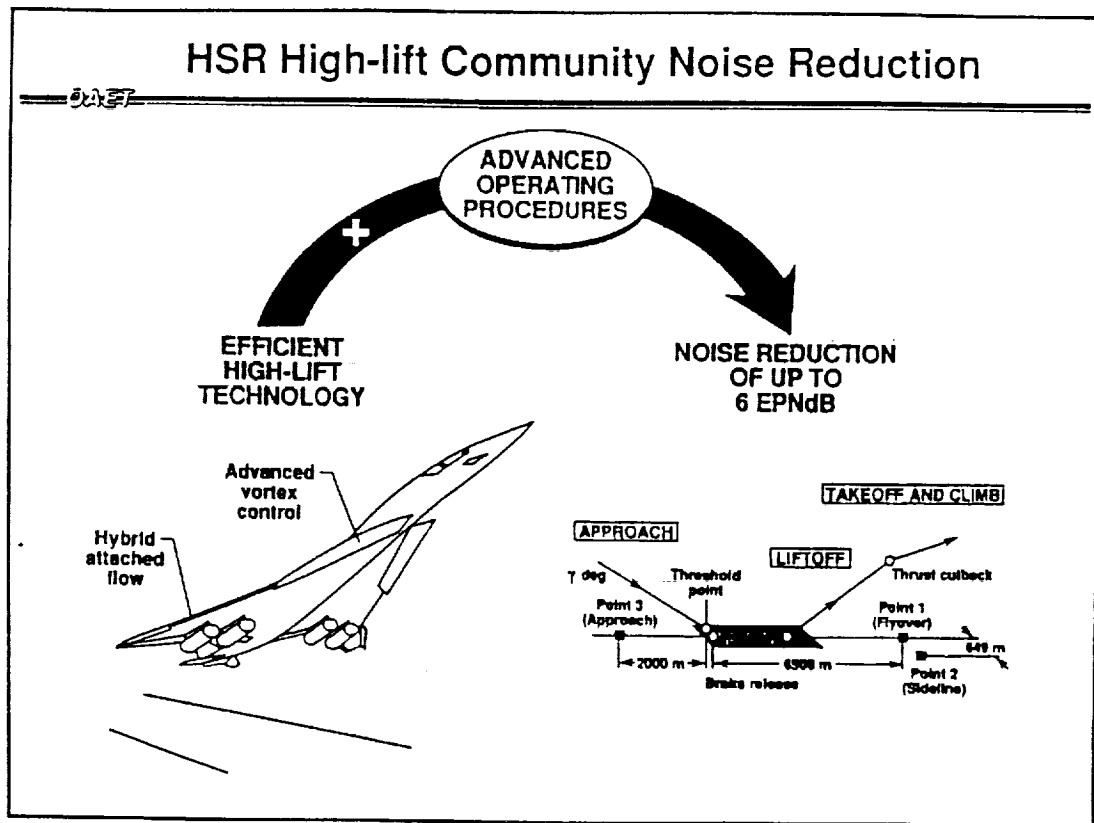
STATUS REPORT

1ST ANNUAL HIGH-SPEED WORKSHOP

MAY 14, 1991

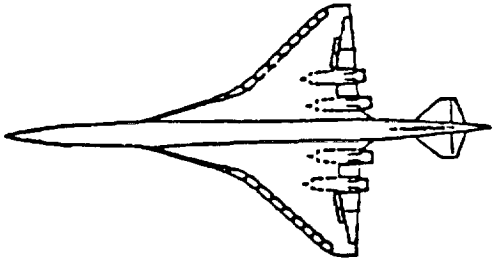
**GEORGE UNGER
MANAGER, VEHICLE AERODYNAMICS
AERODYNAMICS DIVISION
OFFICE OF AERONAUTICS, EXPLORATION AND TECHNOLOGY**

1. This area covers the aerodynamics aspects of meeting the Stage III noise rule including the aeroacoustic prediction of system noise, operating procedures for abatement and high lift devices for more efficient climb out.



1. The goal for this element is a noise reduction of 6 EPNdB thru efficient high lift devices and noise abatement procedures.
2. The goals assume that thrust cutback will be possible while maintaining the same climb angles as today's technology designs. The means that climb lift-to-drag ratios must improve by at least 20%.

HSCT COMMUNITY NOISE TECHNOLOGY Challenge



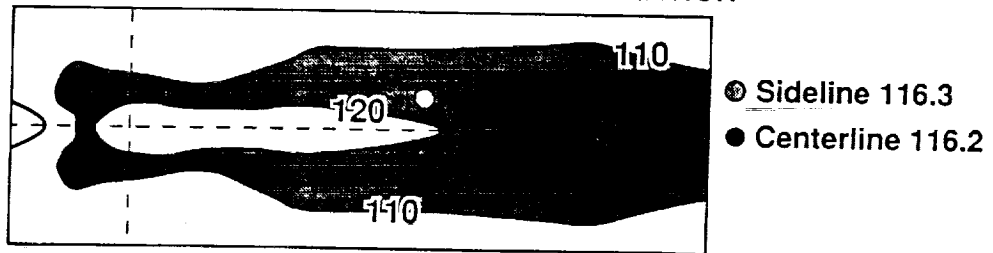
(4) Engines
TOGW = 750,000 #'s
Net engine thrust T = 50,000 #'s
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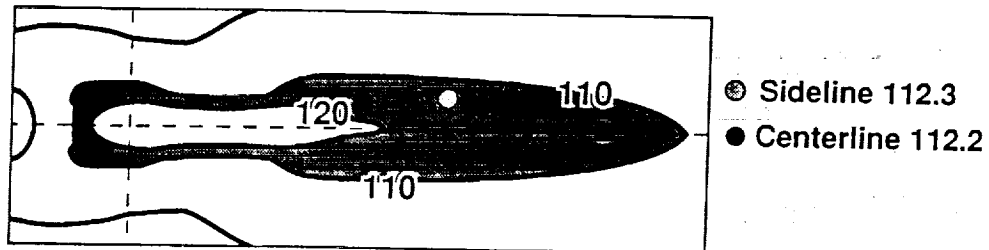
1. The 6 EPNdB savings means that the engine noise suppression requirements can be relaxed - or the engine need not be oversized - or that the margin for design error can be greater and still meet the Stage III limits.

ANOPP SYSTEM NOISE PREDICTION FOR HSCT Effective Noise Level Contours (EPNdB)

100% THRUST, STANDARD LIFT CONFIGURATION



80% THRUST, 30% LIFT INCREASE



⊙, ● NOISE CERTIFICATION POINTS

1. The best way to depict the noise savings is in terms of footprint or ground contour.
2. At 80% thrust, the obvious effect of improved technology is a better L/D. (30% increases lift refers to a higher lift coefficient, enabling lower speeds and hence less drag.)
3. Some leeway may be required in the way the FAA assesses noise impact since the two certification points do not adequately measure total noise impact.

HIGH LIFT SYSTEMS

AERODYNAMICS DIVISION

MILESTONES

FY 1991	FY 1992	FY 1993	FY 1994	FY 1995
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PREDICTIVE METHODOLOGY

Nav.-Stokes
unstructured
grid for high
lift wings

Noise
reduction
due to
high-lift

Screening
of high lift
concepts

3-D CFD
of high lift
concept
modelled

Enhanced
high lift CFD
codes
available

Noise
reduction due
to advanced
configuration

Revise code
per feedback from
industry users

SUPPORTING EXPERIMENTS

NTF test of
leading edge
radius and R_n
effects

Trapped vortex
water tunnel
tested s.scale,
analyzed 3-D N-S

Hybrid LE designs,
vortex flap

Second generation
high-lift concepts.
Advanced models

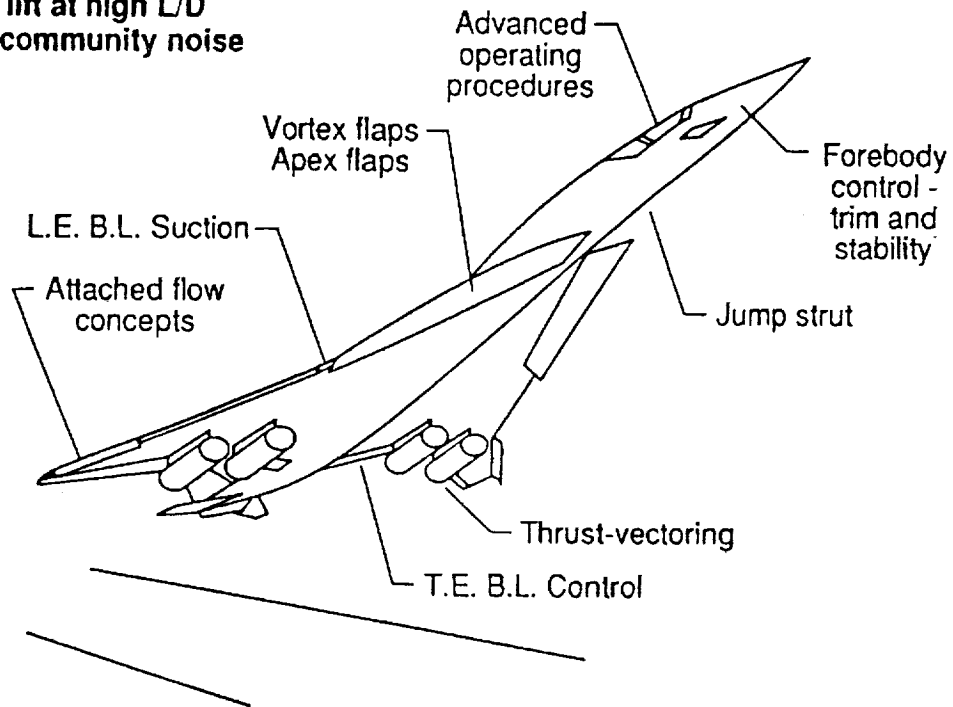
Set of high-lift concepts and
their performance

1. The program plan for high lift is depicted here for the record.
2. The efforts result in wind tunnel tests of various concepts and code validation to match the results. These results will be picked up in Phase II for integration and flight test validation.

HSR HIGH-LIFT ADVANCED CONCEPTS

GOALS

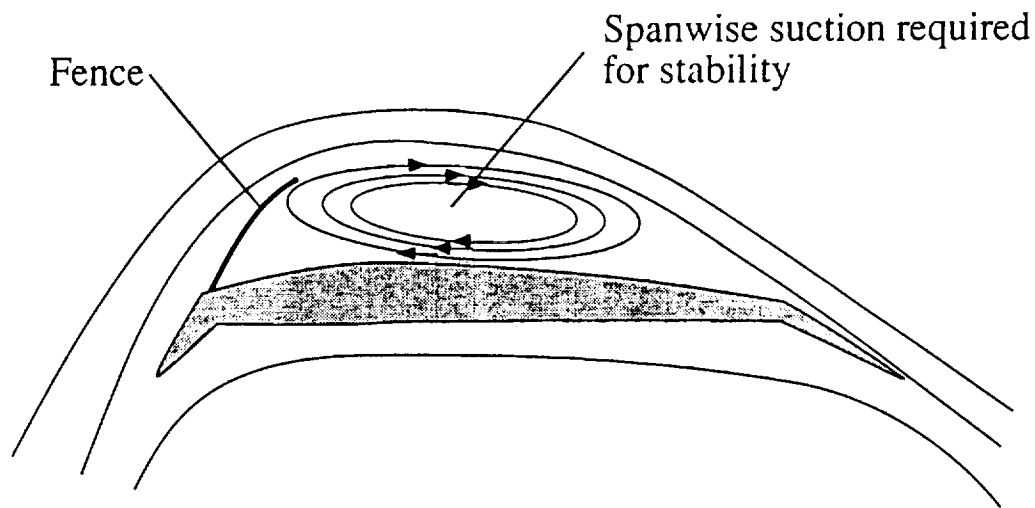
- Early rotation
- High lift at high L/D
- Low community noise



1. This sketch depicts many of the high lift technologies that have been planned.

HSR High-Lift Systems Concept Development

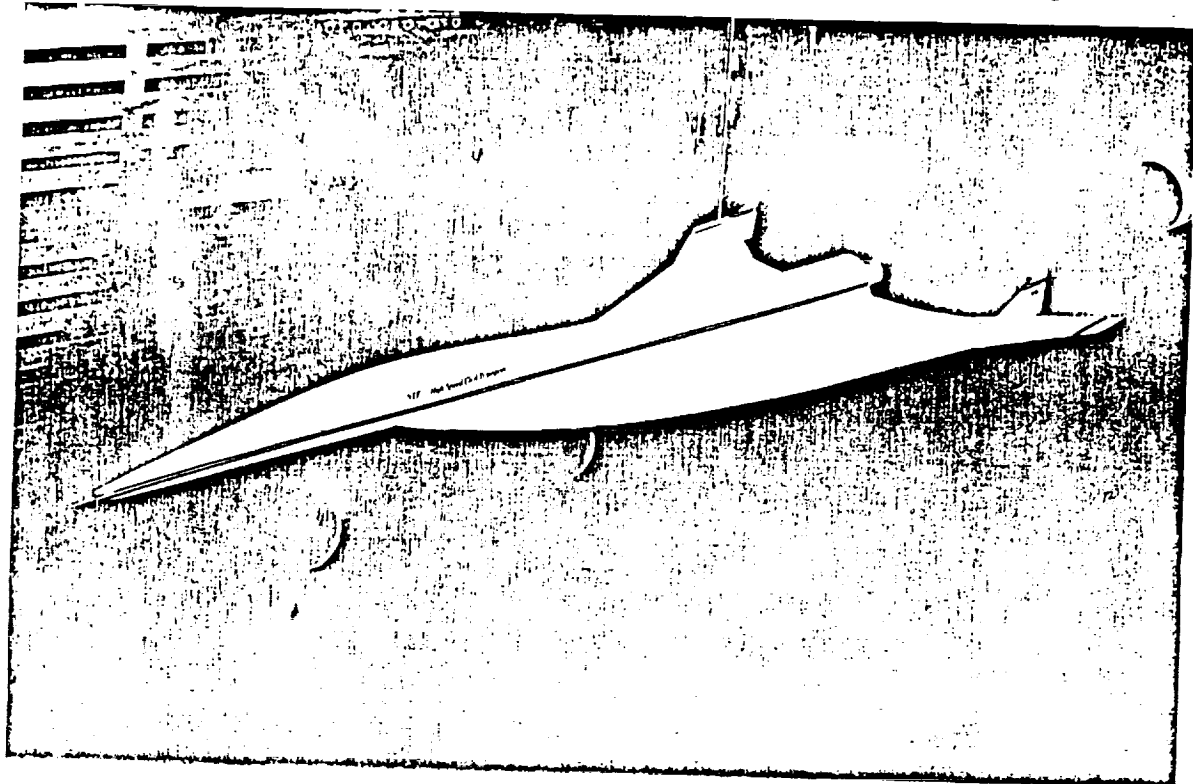
Trapped vortex concept



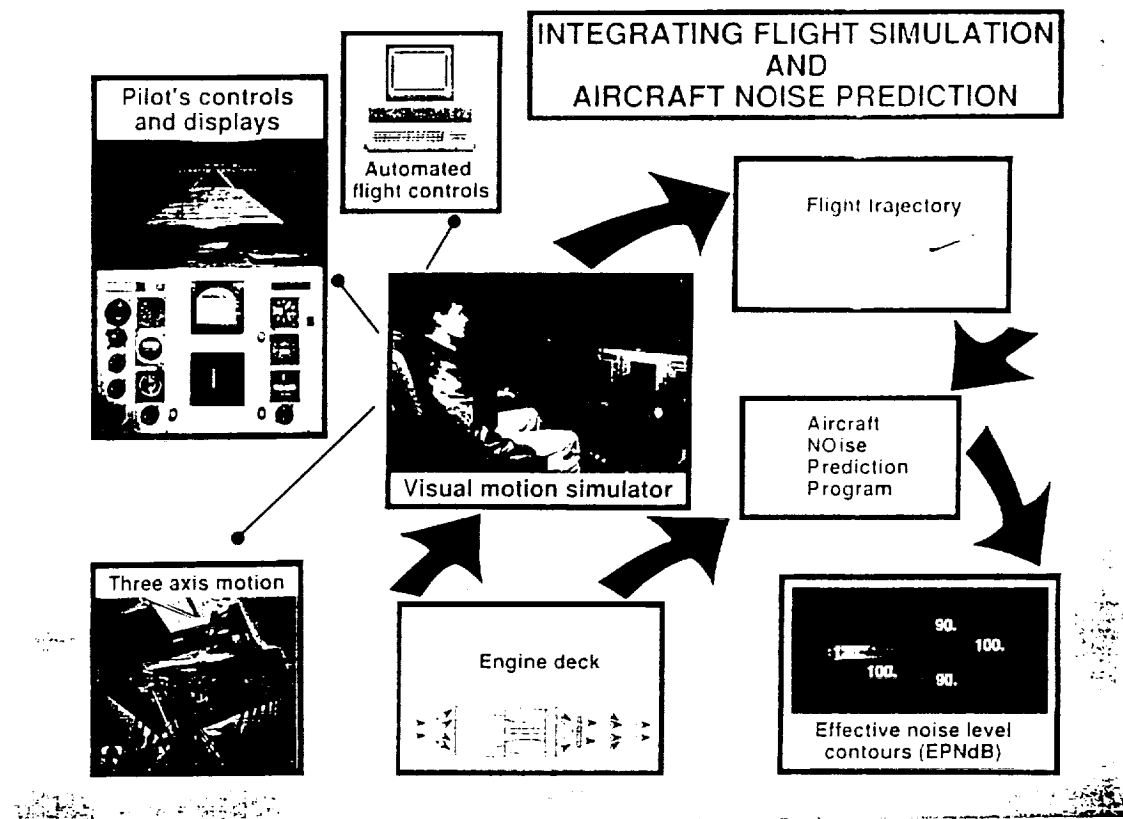
Jim Ross ARC

1. One of the early results from Ames is the trapped vortex concept.
2. The drag was unacceptably high unless a rearward fence was incorporated.
3. Further testing is planned to find ways to eliminate the requirement for spanwise suction on a swept wing.

HIGH-LIFT STUDY IN THE NATIONAL TRANSONIC FACILITY REYNOLDS NUMBER AND LEADING EDGE RADIUS EFFECTS



1. Langley has conducted exploratory testing in its 12-ft, 14x22-ft and NTF wind tunnels.
2. The NTF provides a high Reynolds number similitude for understanding the effects of scaling of model HSR wings.



1. The final test of any of these high lift devices is integration into an aircraft.
2. Depicted here is the logic of testing that integrated aircraft in a piloted simulation that yields flight trajectories and engine settings.
3. These data are then coupled into ANOPP to predict noise contours.
4. First trials of the above procedure have been completed. It will be an extremely useful means of evaluating noise impact quickly.

HIGH LIFT SYSTEMS

STATUS

- ANOPP applied to high lift and operational procedures
- Concept screening initiated
- Piloted simulation of operational procedures

CONCERNS

- Compatibility/integration of high-lift systems with supersonic laminar flow control and low-boom planforms

- 1. There has not been much early success in this element with new high lift devices. The problem is the attendant drag that seems to accompany the higher lift results. In some cases this has led to solutions for a second round of testing.**
- 2. The FAA will have to be an early player in assessing the safety of the low noise, multi-mode takeoff profiles. Automation of takeoff and climb will have to be examined later in the HSR program.**
- 3. It is clear that some high lift devices will not be appropriate for low boom or laminar flow control. There should be a first-pass criteria that recognizes these integration issues.**

COOPERATIVE EFFORTS

- RN and leading-edge radius effects (Boeing)
- Leading-edge BLC/suction system (Boeing)
 - Avoid l.e. separation
 - Simulate high RN conditions
- Wing fence/flap concepts (Boeing)
- Forebody flow control (Boeing)
- Wing apex blowing concepts (Douglas)
- High-lift design methods (Douglas)
- Longitudinal and lateral trim concepts (Boeing & Douglas)
- Piloted simulation of advanced aero and operating procedures for noise reduction (Boeing & Douglas)

1. The high lift element has the lowest funding of any element. It owes its success and progress in part to numerous cooperative activities with industry.

2. The above list contains some of the past and planned cooperative efforts with industry. Obviously more will be planned as clear success can be shown.

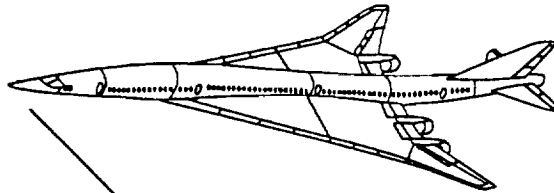
SONIC BOOM RESEARCH

Civil supersonic flight over land is currently not allowed in the U.S. (Ref: FAR 91) and many other places. European HSCT studies seem to assume no solution is possible for the boom problem, and NASA sponsored studies by Boeing and Douglas indicate economic viability for an aircraft that would be primarily limited to over water supersonic operation, and limited subsonic operation over land. However, supersonic overland flight would be a significant economic benefit, and the HSRP is pursuing attractive low boom concepts, including low supersonic speeds over populated areas. By late 1992, enough wind tunnel and subjective response data should be available to allow a system study based decision on low boom feasibility.

SONIC BOOM RESEARCH

- FAR 91 RESTRICTS NORMAL OPERATION OF CIVIL AIRCRAFT IN THE U.S. TO SUBSONIC SPEEDS
- SIMILAR RULES RESTRICT SUPERSONIC AIRCRAFT IN OTHER COUNTRIES
- HSCT STUDIES INDICATE VIABILITY FOR LIMITED SUBSONIC OPERATION OVER LAND
- SUPERSONIC FLIGHT OVER LAND WOULD BE A SIGNIFICANT ECONOMIC BENEFIT
- HSRP GOALS
 - ESTABLISH ACCEPTABILITY CRITERIA
 - PREDICTIVE METHODOLOGY FOR LOW BOOM CONCEPTS
 - VERIFY PREDICTION CAPABILITY
 - SYSTEM ANALYSIS OF TECHNICAL & ECONOMIC PERFORMANCE
- POSSIBLE PROGRAM REDIRECTION IN '92 COORDINATED WITH LOW BOOM RESEARCH PROGRESS

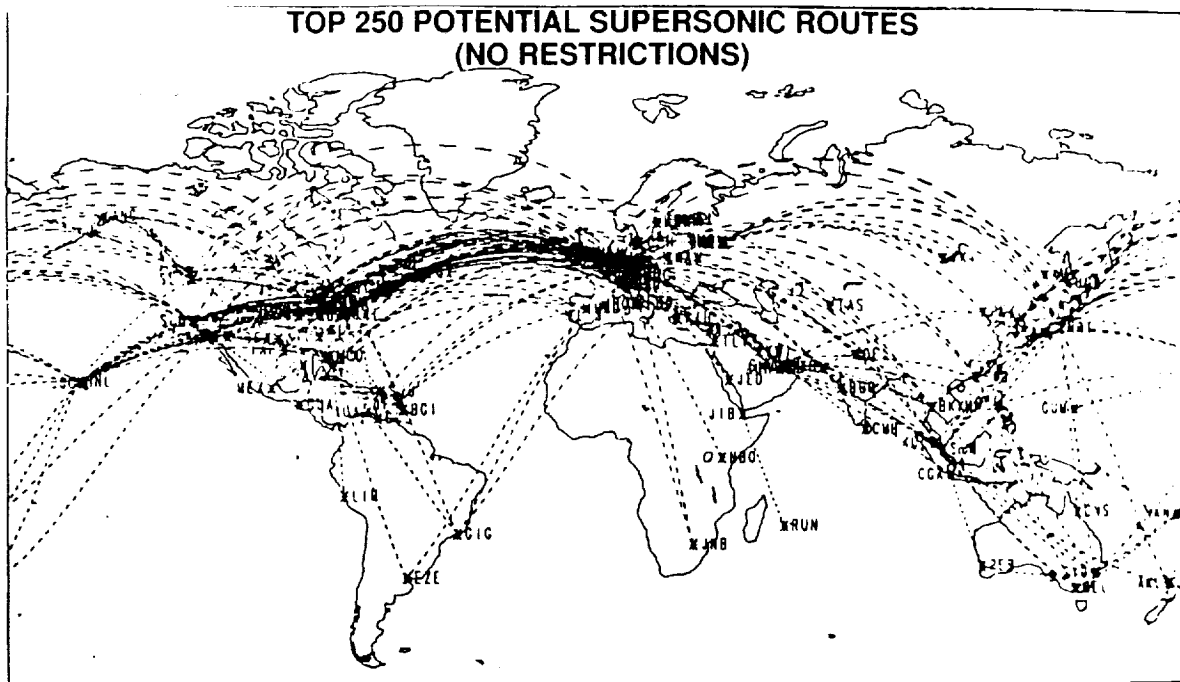
HSR SONIC BOOM TECHNOLOGY



STATUS REPORT 1ST ANNUAL HIGH-SPEED WORKSHOP MAY 14, 1991

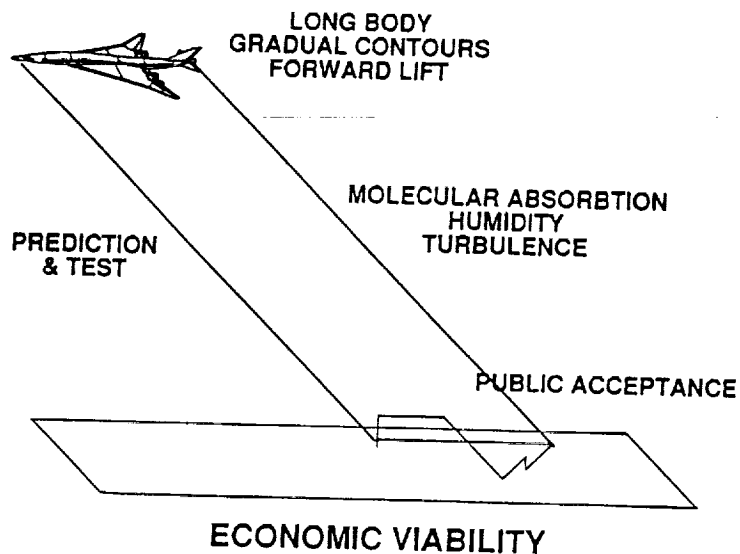
GEORGE UNGER
MANAGER, VEHICLE AERODYNAMICS
AERODYNAMICS DIVISION
OFFICE OF AERONAUTICS, EXPLORATION AND TECHNOLOGY

1. Sonic boom, high lift and supersonic laminar flow control technology areas are covered by the Aerodynamics Division.
2. Kevin Shepherd of Langley helped prepare this charts during a three month stay at Headquarters.
3. George Unger will be officially handing over oversight of these areas to Benjarmin Neumann after this workshop. Benjy comes to Headquarters from NAVAIR.



AVERAGE STAGE LENGTH 3,666 ST MI PERCENT OF LONG-RANGE TRAFFIC — 70 PERCENT

SONIC BOOM ENVIRONMENTAL QUESTIONS



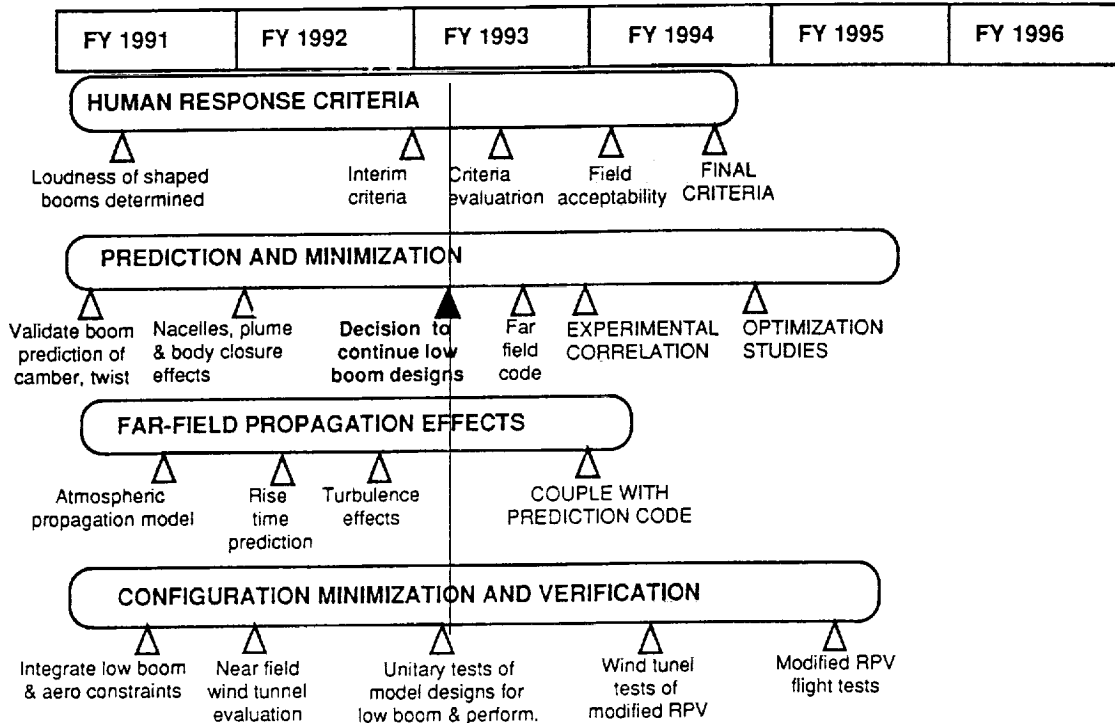
1. The technical questions fall into the 4 areas indicated:

- design tradeoffs - affects economic viability
- propagation through the atmosphere
- prediction of boom signature from aircraft geometry and small-scale wind tunnel testing
- criteria for public acceptance of the low boom signature

2. Not listed at this stage are the effects of acceleration, deceleration and maneuver on the boom signature. These areas will have to be evaluated in any case for near land operation since they can focus the boom into a more intense sound.

SONIC BOOM REDUCTION AERODYNAMICS DIVISION

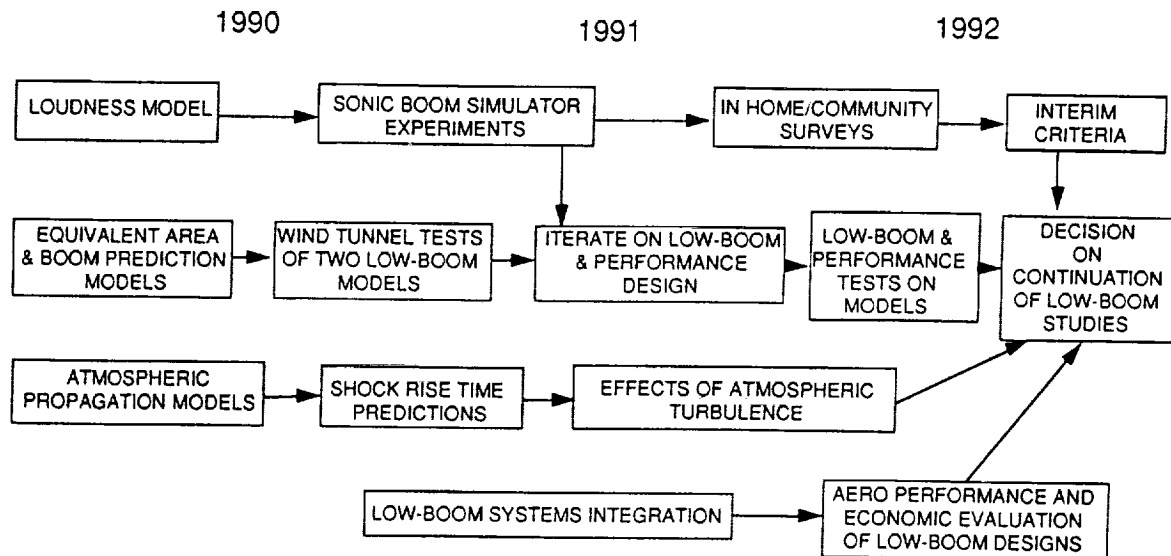
MILESTONES



1. Chart represents the milestones that we are tracking. It is included here for reference.
2. Note that there is a decision in December 1992 to continue exploring low boom designs. The low boom work is viewed with some skepticism as to its practical application. Therefore an early assessment is warranted.

SONIC BOOM RESEARCH PLAN

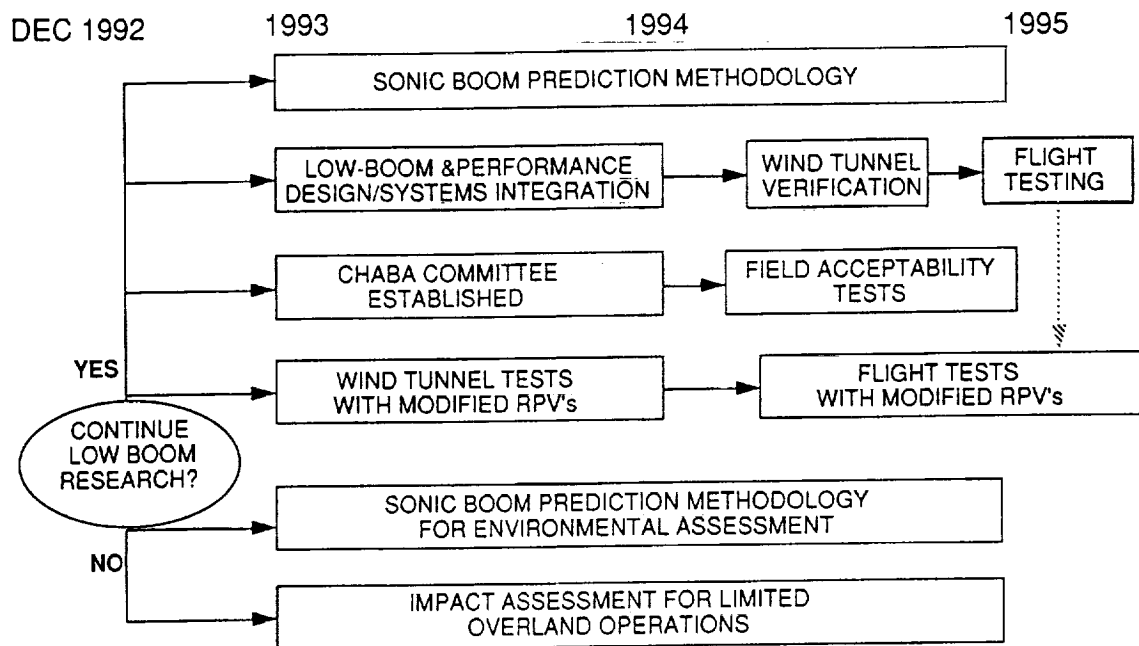
BEFORE DECEMBER 1992



1. The necessary ingredients that must be in hand to make that decision are depicted here.
2. An iterated design is the first step followed by an economic evaluation of its merits. The tradeoff may be added weight per passenger vs. increased market size.
3. Finally an assessment of how close the propagated boom signature comes - on a statistical basis - to the proposed acceptance criteria in the community.

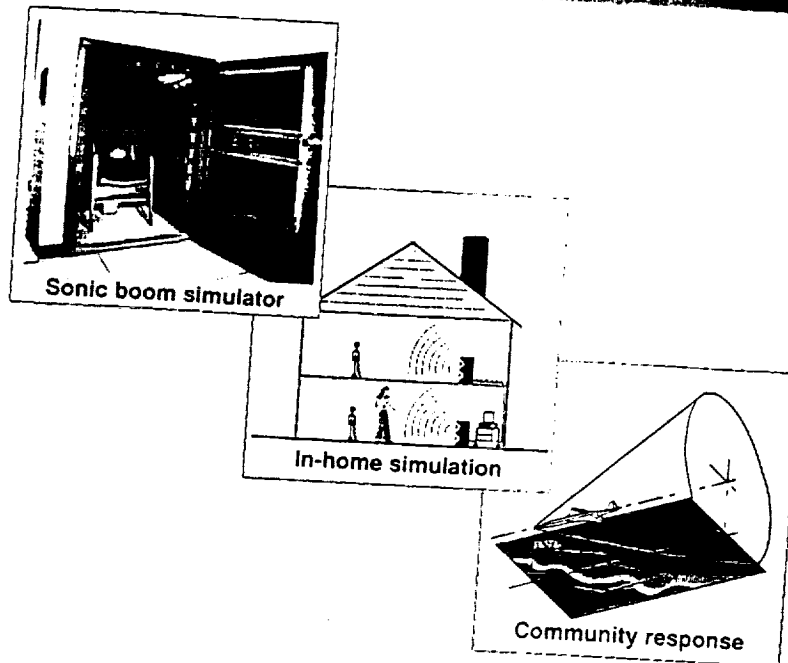
SONIC BOOM RESEARCH PLAN

BEYOND DECEMBER 1992



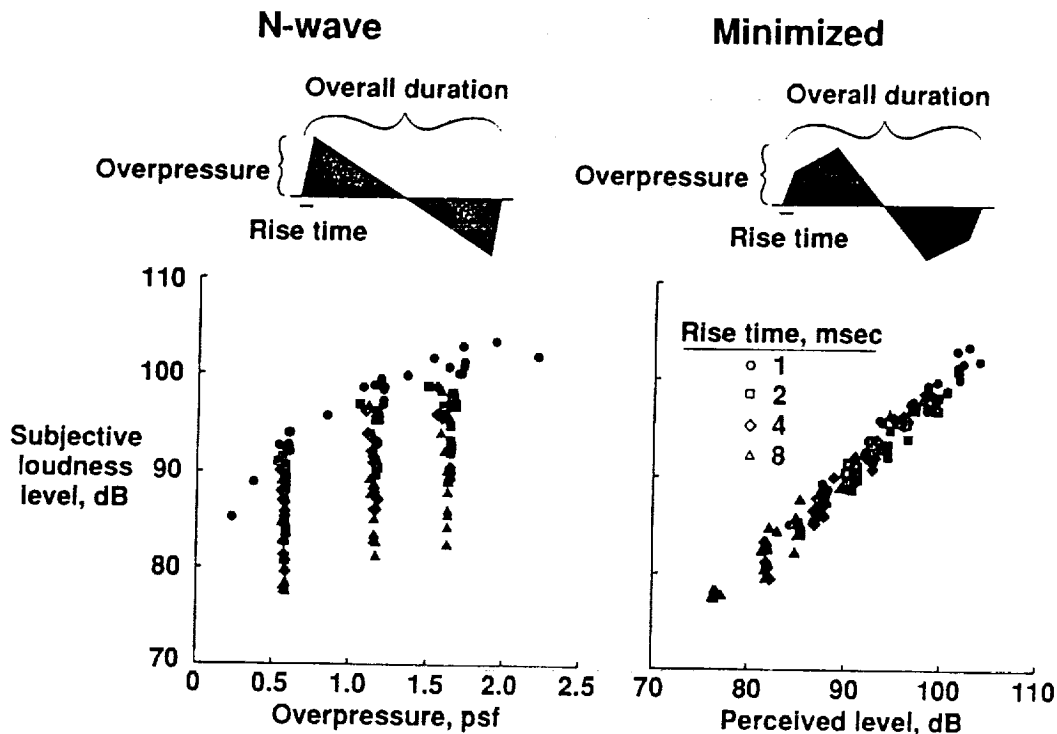
1. Some recent results are presented here.
2. A "boom box" has been constructed to expose subjects to different boom signatures.
3. Work is also underway to test boom exposures inside buildings such as residences.
3. Finally, some effort is being undertaken in cooperation with the USAF to survey communities that were repeatedly boomed by SR-71 flights in the past.

SONIC BOOM ACCEPTABILITY CRITERIA



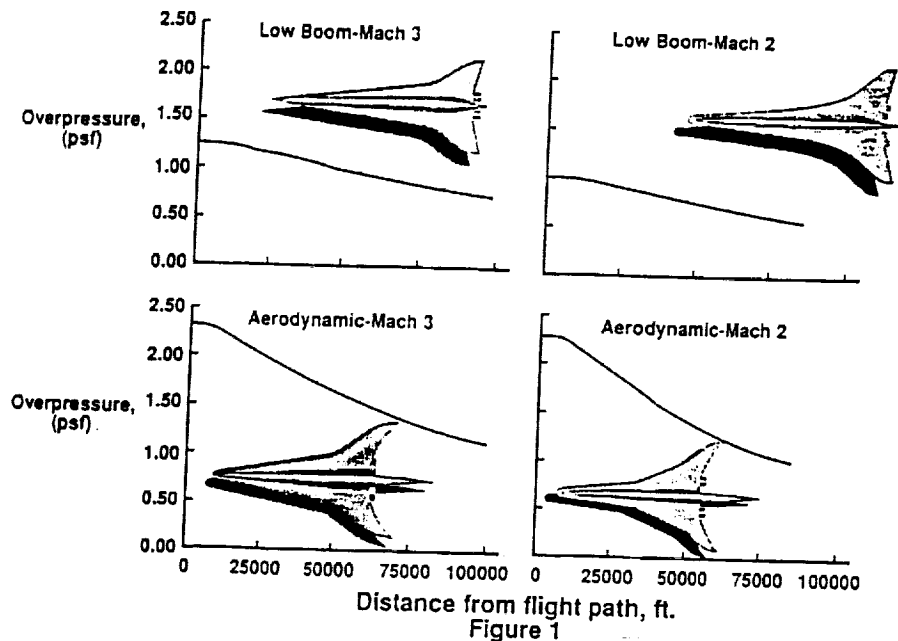
1. If the decision is favorable, then flight testing is in order with modified RPV's. This approach represents the cheapest way to test signature propagation in the real world.
2. Further refinement of the methodology and designs will be necessary.
3. Finally, a committee of experts must be established to supervise and recommend boom acceptability trials.
4. If the decision is to curtail low boom research, then some further research is warranted to understand near land operations, over island booms, and maneuvers, accelerations and decelerations.

PREDICTION OF SUBJECTIVE RESPONSE TO SONIC BOOMS



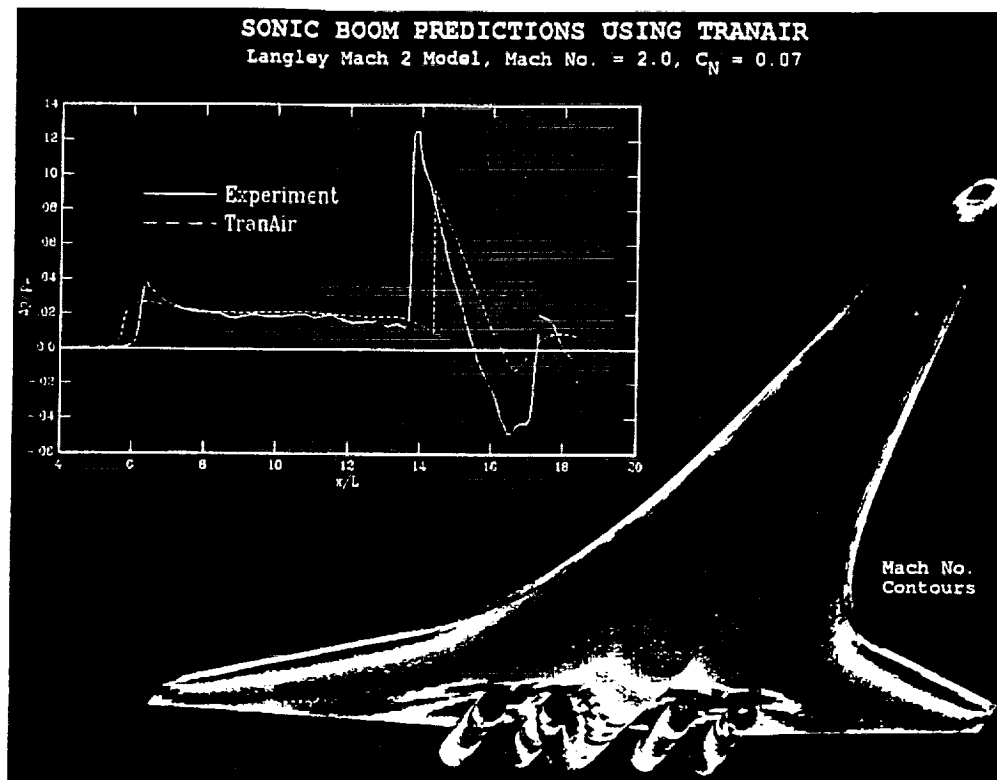
1. The typical "N" wave from a sonic boom is a pressure signature that is characterized by a peak overpressure and a rise time for the initial pressure wave.
2. Making the rise times longer results in a boom sounding less like a crackle or thump and more like a rumble or whump. Peak overpressure affects the intensity and the atmospheric dissipation characteristics. The left chart shows that the shortest rise times (circles) exhibit the most subjective loudness.
3. "Loudness" appears to be the more consistent measure of annoyance, as shown by the right hand chart.
4. Target overpressures are at or below 1 pound per square foot (psf).

SONIC BOOM BOW SHOCK LEVELS AS A FUNCTION OF DISTANCE FROM FLIGHT PATH



1. Another concern of the low boom design was off-axis signature. If the configuration yielded a low overpressure directly under the flight path, would that remain true to the left and right of the center line signature laid on the ground?

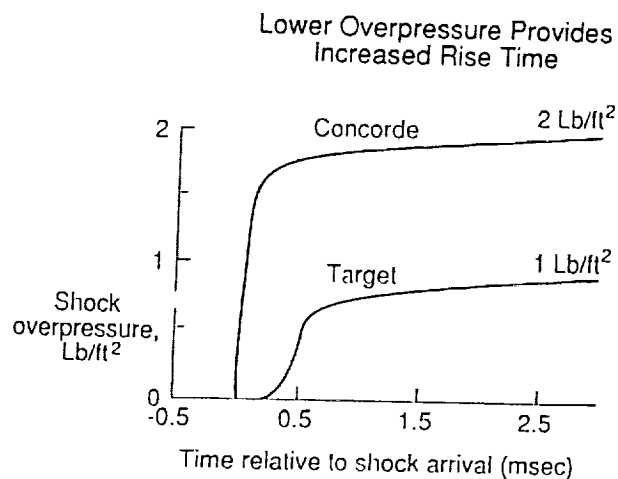
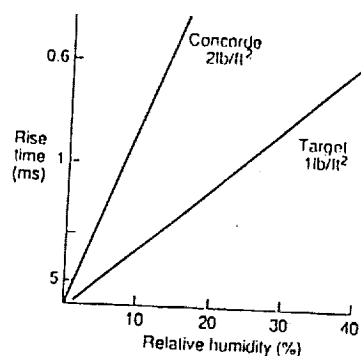
2. The top figures show that the low boom overpressure does not rise with increasing distance along the sideline. Indeed, even at 100,000 feet (19 miles) perpendicular to the flight path axis, the low boom design has a lower overpressure than a design that would not have considered sonic boom as a design parameter.



1. Another concern is the reliable prediction of the boom pressure waves from analytical descriptions of the aircraft geometry.
2. Tests were run in the Ames and Langley Unitary tunnels to get pressure signatures close to and some distance (3 body lengths) away from the center line.
3. Except for support strut interference at the back of the model, TRANAIR does a reasonable job of predicting initial overpressures.
4. The peak pressure spike at $x/l = 14$ is due to the blocked engine inlets which will not be present in future tests.
5. The comparison of tests in the Ames And Langley tunnels shows that the smaller test section of the Langley facility is quite adequate for boom testing on these models (which are roughly 12" in length).

ATMOSPHERIC ABSORPTION EFFECTS ON SONIC BOOM WAVE FORMS

Lower Overpressure Less Sensitive
to Humidity Effects



1. Propagation results to date have shown favorable effects when compared to the higher overpressures of the Concorde SST.
2. Humidity, which reduces rise time by allowing faster transport of the acoustic wave, has less dramatically less impact for a 1 psf signature.
3. Similarly, molecular absorption increases rise time for a more benign signature.

SONIC BOOM REDUCTION

STATUS

- Methods for low boom design validated by wind tunnel testing
- Atmospheric absorption compounds benefit of boom minimization
- Human response studies confirm substantial benefit of boom minimization

CONCERNS

- Configuration compatibility with high-lift goals

- 1. Progress in this area has been rapid and continues to show promise.**
- 2. Some form of boom minimization may be attractive in a baseline HSCT if only to recognize the problems with near land booms.**
- 3. The decision to continue working towards a low boom design requires an understanding of the integration issues. The study tasks identified for this concern may not be sufficient to answer all the issues.**

HSCT WEIGHT REDUCTION RESEARCH

In general, HSCT weight reduction would benefit environmental compatibility as well as economics, with a larger direct payoff for emissions and sonic boom. However, economic benefits of weight reduction are critical.

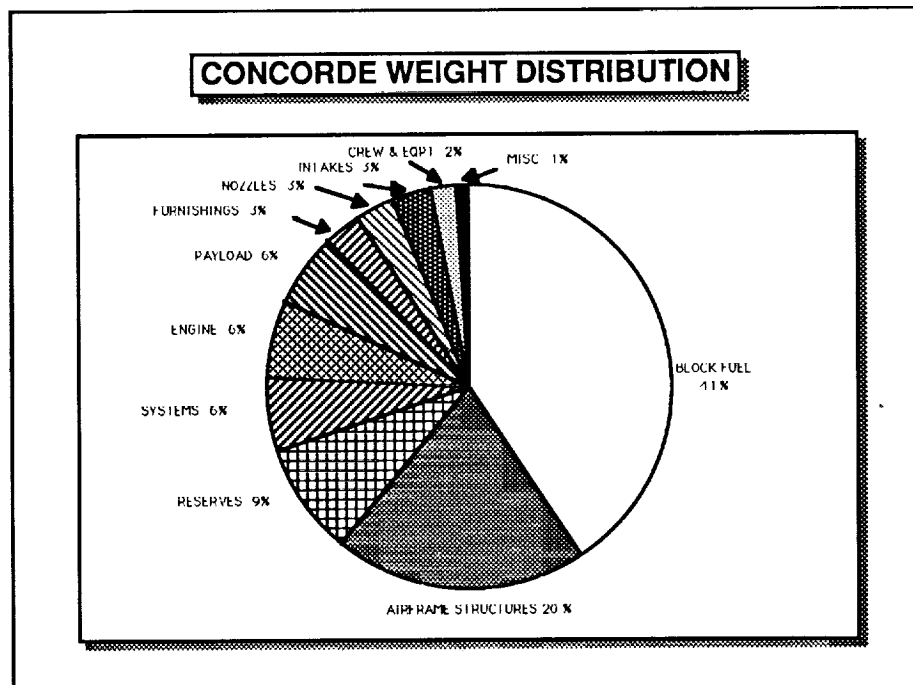
HSCT WEIGHT REDUCTION RESEARCH

- **ENVIRONMENTAL IMPACT**
 - EMISSIONS & SONIC BOOM APPROXIMATELY PROPORTIONAL TO AIRCRAFT WEIGHT
 - NOISE LOGARITHMICALLY PROPORTIONAL TO AIRCRAFT WEIGHT
- **ECONOMIC IMPACT**
 - FUEL IS LARGEST WEIGHT COMPONENT
 - SMALL PAYLOAD FRACTION PROVIDES HIGH LEVERAGE FOR DESIGN TRADES
- **HSRP ELEMENTS**
 - SUPERSONIC LAMINAR FLOW CONTROL RESEARCH
 - MATERIALS & STRUCTURES SYSTEMS TECHNOLOGY (PHASE II)

CONCORDE WEIGHT DISTRIBUTION

These Concorde data typify qualitative aspects of HSCT weight distribution. Advanced design should allow a somewhat more favorable distribution for economics (e.g., less structure, more payload). However, fuel will continue to be a very large fraction at about 50 percent, which shows the importance of all forms of performance efficiency improvements, including aerodynamics, propulsion, and structure. The small payload fraction shows the high leverage benefits for small reductions in other weight contributors, and emphasizes the importance of HSCT weight reduction efforts.

The HSRP includes supersonic laminar flow control research as a promising means for weight reduction. A parallel Materials & Structures Systems Technology Program with more broad aircraft goals has also begun to study HSCT applications as a precursor for Phase II of the HSRP.



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HSR SUPERSONIC LAMINAR FLOW CONTROL TECHNOLOGY

STATUS REPORT

1ST ANNUAL HIGH-SPEED WORKSHOP

MAY 14, 1991

**GEORGE UNGER
MANAGER, VEHICLE AERODYNAMICS
AERODYNAMICS DIVISION
OFFICE OF AERONAUTICS, EXPLORATION AND TECHNOLOGY**

- 1. This element represents the largest aerodynamic element and, perhaps the one with the most controversy.**
- 2. The success of the subsonic laminar flow control flight testing and preliminary testing at supersonic speeds has led to the belief that maintaining significant laminar flow is possible for the HSCT.**
- 3. The major questions require demonstration as I shall outline.**

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SUPERSONIC LAMINAR FLOW CONTROL

BENEFITS

- REDUCTIONS IN

SONIC BOOM LEVELS

COMMUNITY NOISE

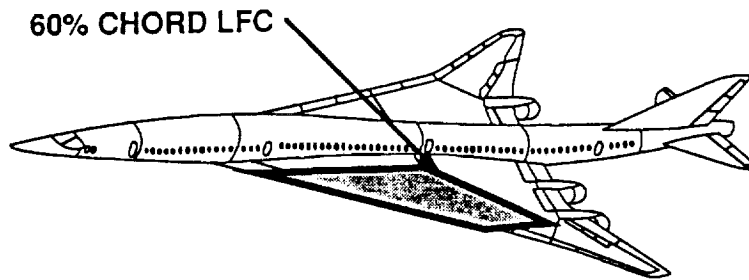
ENGINE EMISSIONS

• LIFT / DRAG INCREASE	12 - 17%	or RANGE +10 - 12%
• FUEL BURN DECREASE	14 - 18%	
• GROSS WEIGHT DECREASE	7 - 10%	

(NASA CR-181817)

- 1. The above summarizes the benefits predicted on the basis of a re-designed aircraft that incorporated SSLFC from the start.**
- 2. The risk of using the SSLFC as a baseline design is the converse of the above: failure will result in the opposite of the benefits. That is to say, if the production airplane was designed for SSLFC with the expectation of the benefits of reduced fuel usage and it did not occur, there would be a shortfall in range of 10-12%.**

SSLFC QUESTIONS



CROSS FLOW /LEADING EDGE CONTAMINATION
SUCTION POWER REQUIREMENTS
OFF DESIGN PERFORMANCE

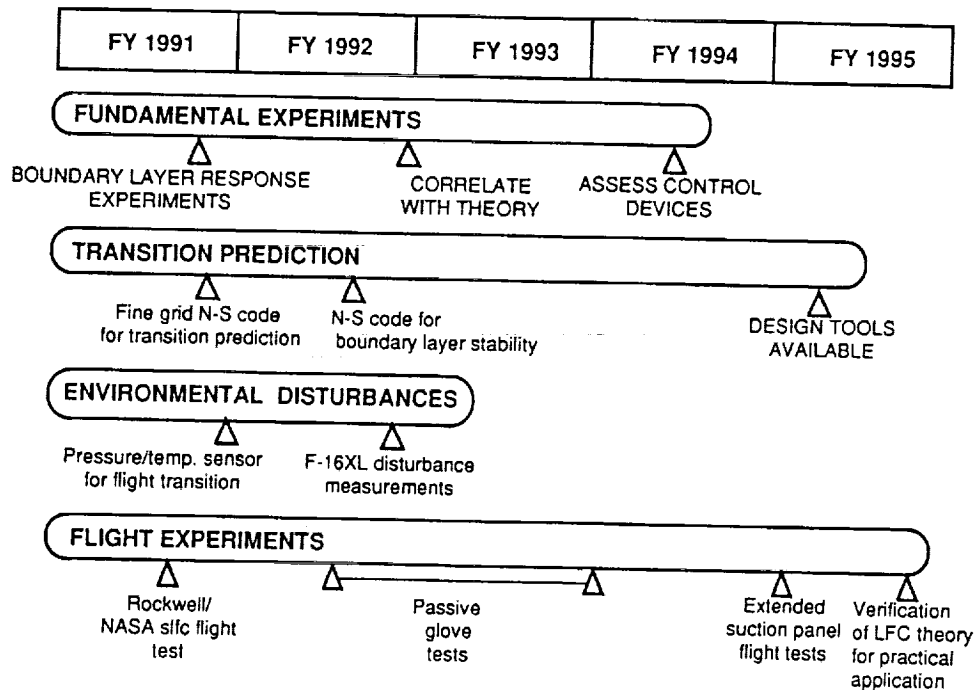
SYSTEM INSTALLATION
REQUIREMENTS

DEMONSTRATE
@ LARGE SCALE R.N.

1. The leading questions I referred to earlier are depicted here.
2. These questions have focused this element on a large scale demonstration of SSLFC on an F-16XL aircraft. Smaller scale experiments simply do not represent the actual hardware and results that are expected on a production HSCT.

SUPERSONIC LAMINAR FLOW CONTROL AERODYNAMICS DIVISION

MILESTONES

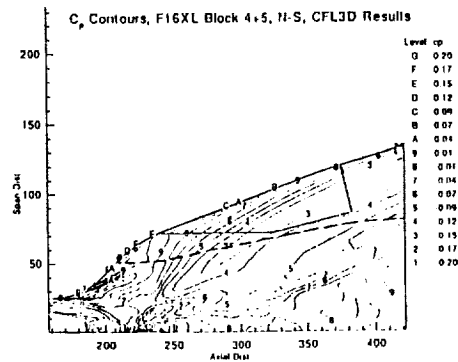


1. The program plan is included here for the record.

2. The goal is the earliest possible flight test of a full system glove on the F-16XL in order to influence the baseline HSCT design.

SUPERSONIC LAMINAR FLOW CONTROL

COMPUTATIONAL TOOLS IN PLACE

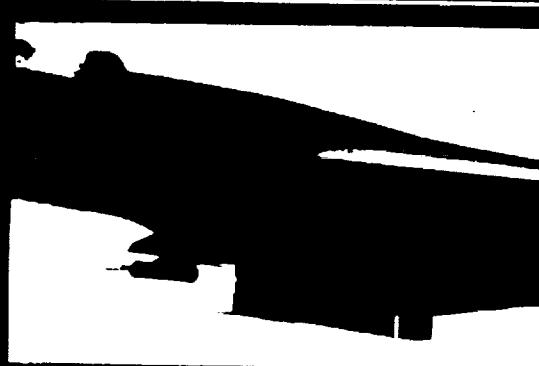


- MEAN FLOW ANALYSES FROM 2 NAVIER-STOKES CODES
- LINEAR BOUNDARY STABILITY CODE, MODIFIED FOR 3-D COMPRESSIBLE FLOW
- COUPLING OF N-S RESULTS TO STABILITY CODE YIELDS ACCURATE PROFILES FOR TURBULENT TRANSITION WITH AND WITHOUT SUCTION
- CONTAMINATION ALONG LEADING EDGE AND REAR OF CANOPY UNDERSTOOD

~~C4~~

Advanced Sensors For Transition Research

Ames Fluid Mechanics Laboratory



sensor will be mounted here

F104 Flight Test Fixture

- Temperature/Pressure Sensitive Paint Feasibility Study
- Flight-qualification
- Use of sunlight as excitation source

F16XL Program

- Temperature/Pressure Sensitive Paint
- Liquid Crystal Shear Sensors

video camera

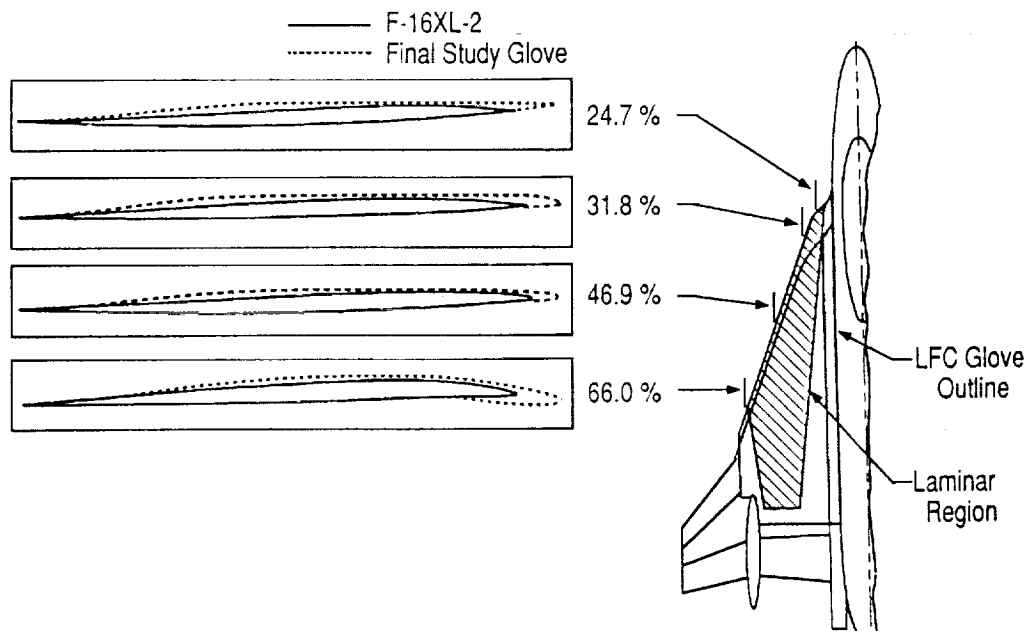
active glove



1. A sub-element of this activity is the development of sensors that accurately measure the transition point between laminar flow and turbulence onset.

2. The slide (reproduced here in poor quality) shows a combination of sensors that will be incorporated on the SSLFC test aircraft.

DAC F-16XL-2 SLFC DESIGN FEASIBILITY STUDY

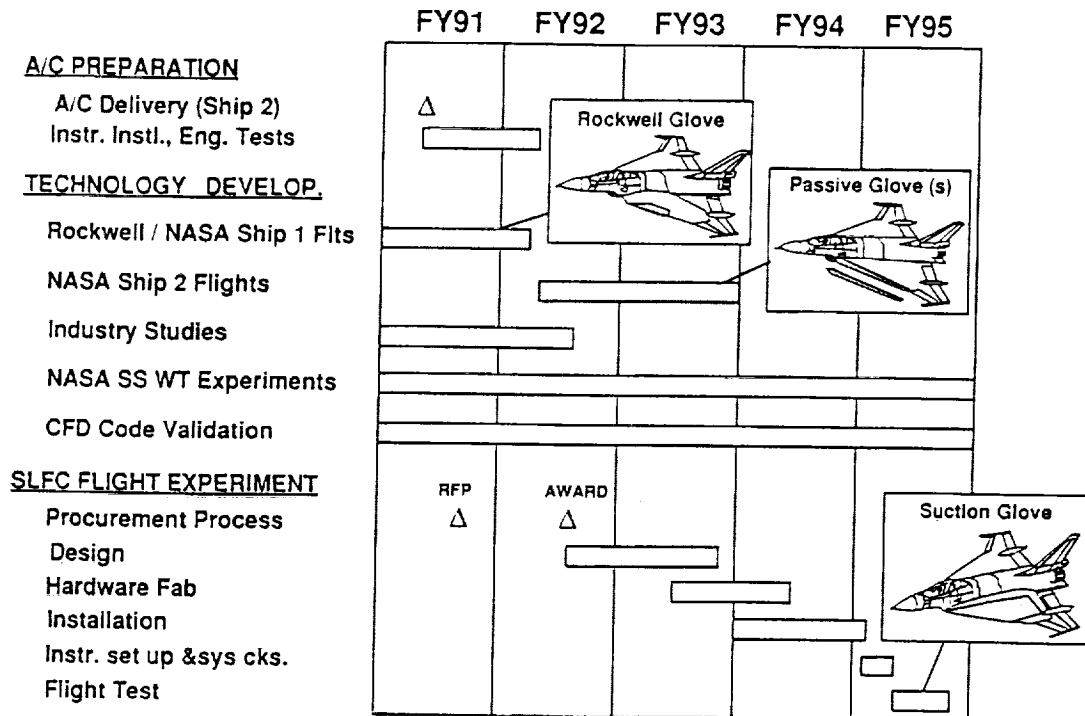


1. An early result of the design activity is shown above. Douglas has shown analytically that a proper glove can be wrapped around the wing without penetrating the existing contours of the F-16XL.

2. The design will have the flexibility of testing different suction regions at varying suction rates to examine the system design requirements.

FISHER 40
5/2/91

F-16XL SUPERSONIC LAMINAR FLOW CONTROL EXPERIMENT



1. The project plan for the flight testing is shown here.
2. Key to the success of the coordination of the activity is the use of both F-16XL aircraft to provide a broader basis to the final design that is demonstrated.

SUPERSONIC LAMINAR FLOW CONTROL

STATUS

- SLFC achieved by Rockwell/NASA flight test
- F-16XL glove design for 60% chord SLFC is feasible (Douglas)
- Codes in place for transition in supersonic swept wings

CONCERNS

- Compatibility/integration of SLFC with leading edge high-lift devices

- 1. The Rockwell tests are encouraging and the data is being used to understand the limitations of the F-16XL.**
- 2. Without some understanding of the integration issues, it will be difficult to assess the full merits of some high lift devices. In addition, the availability of suction may offer high lift ideas that merit evaluation.**
- 3. Integration with low sonic boom ideas is also a concern. Except for possible leading edge compromises in the airfoils, this issue is unclear.**

MAJOR ACCOMPLISHMENTS TO DATE

Significant accomplishments have been achieved in the first 1 1/2 years of the HSRP. In particular, research results promise achievement of emissions and noise goals, and the feasibility of low boom concepts. However, much additional effort will be necessary before the overall program is successfully concluded.

MAJOR ACCOMPLISHMENTS TO DATE

- **ATMOSPHERIC RESEARCH**
 - 2-D MODEL ASSESSMENT
 - CHEMISTRY LAB EXPERIMENTS
 - FIELD CAMPAIGN PLANNING
- **EMISSIONS REDUCTION**
 - ADDITIVES EVALUATION
 - CFD APPLICATION
 - FLAMETUBE DEMONSTRATION OF LPP CONCEPT
- **SOURCE NOISE REDUCTION**
 - CFD APPLICATION
 - MIXER/EJECTOR NOZZLE AEROACOUSTIC PERFORMANCE
- **COMMUNITY NOISE**
 - ANOPP APPLICATION
 - HIGH-LIFT CONCEPT SCREENING
 - PILOTED SIMULATION OF OPERATIONAL PROCEDURES
- **SONIC BOOM**
 - CFD APPLICATION
 - PHASE I LOW BOOM CONCEPT W.T. TESTS
 - SUBJECTIVE RESPONSE EVALUATION
- **SUPERSONIC LAMINAR FLOW CONTROL**
 - CFD APPLICATION
 - FLOW MEASUREMENT PROCEDURES
 - F-16XL AIRCRAFT ACQUISITION

PROGRAM SUMMARY

In the near term, progress towards achievement of program goals will demonstrate readiness for initiation of a more vehicle focussed technology program that, in turn, would complete the foundation for an industry aircraft development program. As indicated earlier, it is currently planned to begin Phase II of the HSRP in FY 93.

HIGH-SPEED RESEARCH PROGRAM

PROGRAM SUMMARY

A SUCCESSFUL CONCLUSION OF THE INTERRELATED RESEARCH EFFORTS WILL DEMONSTRATE:

EMISSIONS

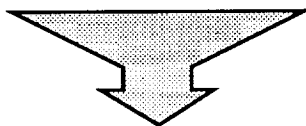
- Feasibility of 90% NO_x Reduction to EI = 3 to 8
- Validity of HSCT Ozone Effect Predictions
- Acceptability of Emission Levels

AIRPORT COMMUNITY NOISE

- Feasibility of Economically Viable Compliance with FAR 36 - Stage 3

SONIC BOOM

- Feasibility of Acceptable Supersonic Overflight or Economic Viability Assuming Subsonic Overflight Restriction



READINESS FOR INITIATION OF HIGH-LEVERAGE TECHNOLOGY DEVELOPMENT PROGRAM

WORKSHOP TECHNOLOGY SESSIONS

The purpose of the following workshop sessions is to describe important technological accomplishments in the HSRP, to review the content of each program element, and to discuss planned activities and key milestones. In general, each session should begin with an overview, and be followed by presentations summarizing the key results to date. Sufficient discussion time should be allowed for active involvement of technical specialists within each program element. Following completion of each technology session, chairmen and rapporteurs are to prepare reports for HSRP management, summarizing session presentations and recommendations regarding midcourse corrections in objectives and plans. Emphasis should be on program level milestones.

FIRST ANNUAL HIGH-SPEED RESEARCH WORKSHOP

WORKSHOP TECHNOLOGY SESSIONS

WEDNESDAY, MAY 15, 8:30 A.M. THRU THURSDAY, MAY 16, NOON

OBJECTIVES

- **OVERVIEW OF STATUS AND PROGRESS**
- **PAPERS SUMMARIZING KEY RESULTS, PLANS, ETC**
- **OPEN DISCUSSION**
 - **ASSESSMENT OF PROGRESS VS PLANS**
 - **CONSIDERATION OF MIDCOURSE CORRECTIONS**
 - **RECOMMENDATIONS**
- **PREPARATION OF SESSION CHAIRMEN'S REPORTS TO PROGRAM MANAGEMENT**

SESSION CHAIRMEN REPORTS TO PROGRAM MANAGEMENT

In general, only session chairmen and rapporteurs are invited to attend the feedback session. Thirty minutes has been allotted for each oral report, and about ten minutes of the allotted time should be reserved for questions and discussion. Written reports are also to be provided, but appropriate charts from the oral presentation should suffice. Written responses to recommendations will be provided within a few weeks following the workshop.

SESSION CHAIRMEN REPORTS TO PROGRAM MANAGEMENT		
LANGLEY RESEARCH CENTER BUILDING 1218, ROOM 107		
Thursday, May 16		
2:00 p.m.	Source Noise	Blaha/Preisner
2:30 p.m.	Aeroacoustics Analysis & Community Noise	Golub/Soderman
3:00 p.m.	Airframe Systems Studies	Dollyhigh/Kidwell
3:30 p.m.	Propulsion Systems Studies	Strack/Fishbach
4:00 p.m.	Airframe/Propulsion Integration	Batterton/Nelms
4:30 p.m.	Emissions Reduction	Niedzwiedz/Langhoff
5:00 p.m.	Airframe & Engine Materials	Tenney/Herbell
Friday, May 17		
8:30 a.m.	Atmospheric Effects	Remsberg/Gross
9:00 a.m.	Laminar Flow Control	Fischer/Wolf
9:30 a.m.	High-Lift	Gilbert/Ross
10:00 a.m.	Sonic Boom (Aerodynamic Performance)	Darden/Hicks
10:30 a.m.	Sonic Boom (Human Response & Atm Effects)	Shepherd/McCurdy & McAninch/Willshire
11:00 a.m.	Break	
11:15 a.m.	Executive Session	
Noon	Adjourn	

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Session II. Airframe Systems Studies

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Session II. Airframe Systems Studies

NASA High-Speed Civil Transport Studies--Airframe Systems Studies Review
Frank D. Neumann, Boeing Commercial Airplane Group

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NASA High-Speed Civil Transport Studies

Airframe Systems Studies Review

NASA High-Speed Research Workshop

May 15, 1991

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HSCT MISSION PERSPECTIVE

The reason for the renewed interest in the HSCT is because our marketing projections are telling us that there will be 500,000 people every day wanting to fly across the Atlantic or the Pacific by the time a fleet of HSCT's will be in service. This creates a potential market for over 1,000 HSCT's.

Required range is longer than for either Concorde or the US SST, which were designed for the North Atlantic.

Payload is two to three times that of Concorde because of the larger market; providing us with the improved economies of scale.

The airplane will also be twice as big as Concorde, but in the same weight class as the 747.

The airplane has to meet Stage III noise goals, which means it has to be much quieter than Concorde (approx. 15 EPNdB).

To capture the large potential market, the airplane must be affordable for the majority of air travellers. Our goal are fares no higher than 10% above equivalent subsonic fares.

HSCT Mission Perspective

	Concorde	U.S. SST	HSCT
Market	North Atlantic	North Atlantic	Atlantic and Pacific
Range, nmi	3,500	3,500	5,000-6,000
Payload (passengers)	103	200	250-300
TOGW, lb	400,000	750,000	800,000
Community noise requirements	None	Stage II	Stage III
Revenue required, cents/RPM	87	60	10

HIGH SPEED RESEARCH- SYSTEMS STUDIES GOALS

The goals of the airplane systems studies are consistent with Phase I of the NASA High Speed Research Program: provide realistic configurations to assess whether or not an HSCT could be environmentally acceptable by exploiting advanced technologies, identify innovative high-risk technologies, and prioritize those technologies for further development during Phase II of the NASA High Speed Research Program.

High-Speed Research - Systems Studies Goals

Maintain direction and focus on realistic configurations:

- Environmental issues technologies
- Innovative, high-risk technologies
- Technology prioritization and timing

COMMERCIALLY VIABLE HSCT

The process that we must use to determine whether we have a commercially viable HSCT or not is shown in this Figure. This process illustrates the systems studies approach of integrating the requirements for:

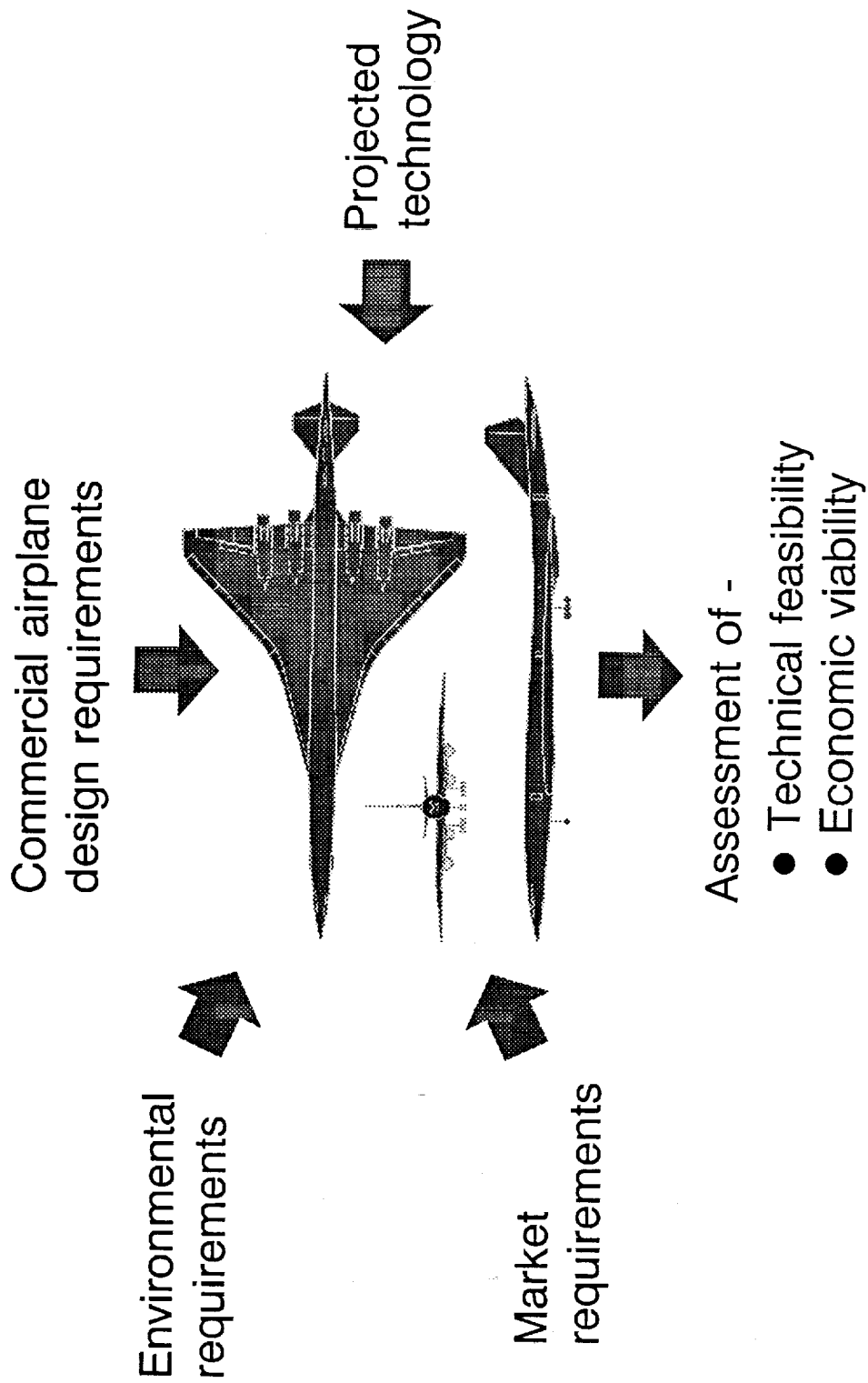
- 1) practical commercial airplane designs
- 2) emissions and noise
- 3) the market in terms of payload, range and fare

with the projected technology advances into a practical airplane design and then determining:

- 1) the designs' technical feasibility
- 2) its' economic viability, and
- 3) needed technology developments



Commercially Viable HSC



HSCT AIRFRAME SYSTEMS STUDIES

Boeing has been participating with NASA in HSCT systems studies under the High Speed Research Program since 1986.

There have been five program phases. Their objectives and timing are summarized in the Figure.

During Phase I we looked at a very broad range of concepts, with speeds from Mach 2 to 10. We assessed technologies, environmental issues and market physics.

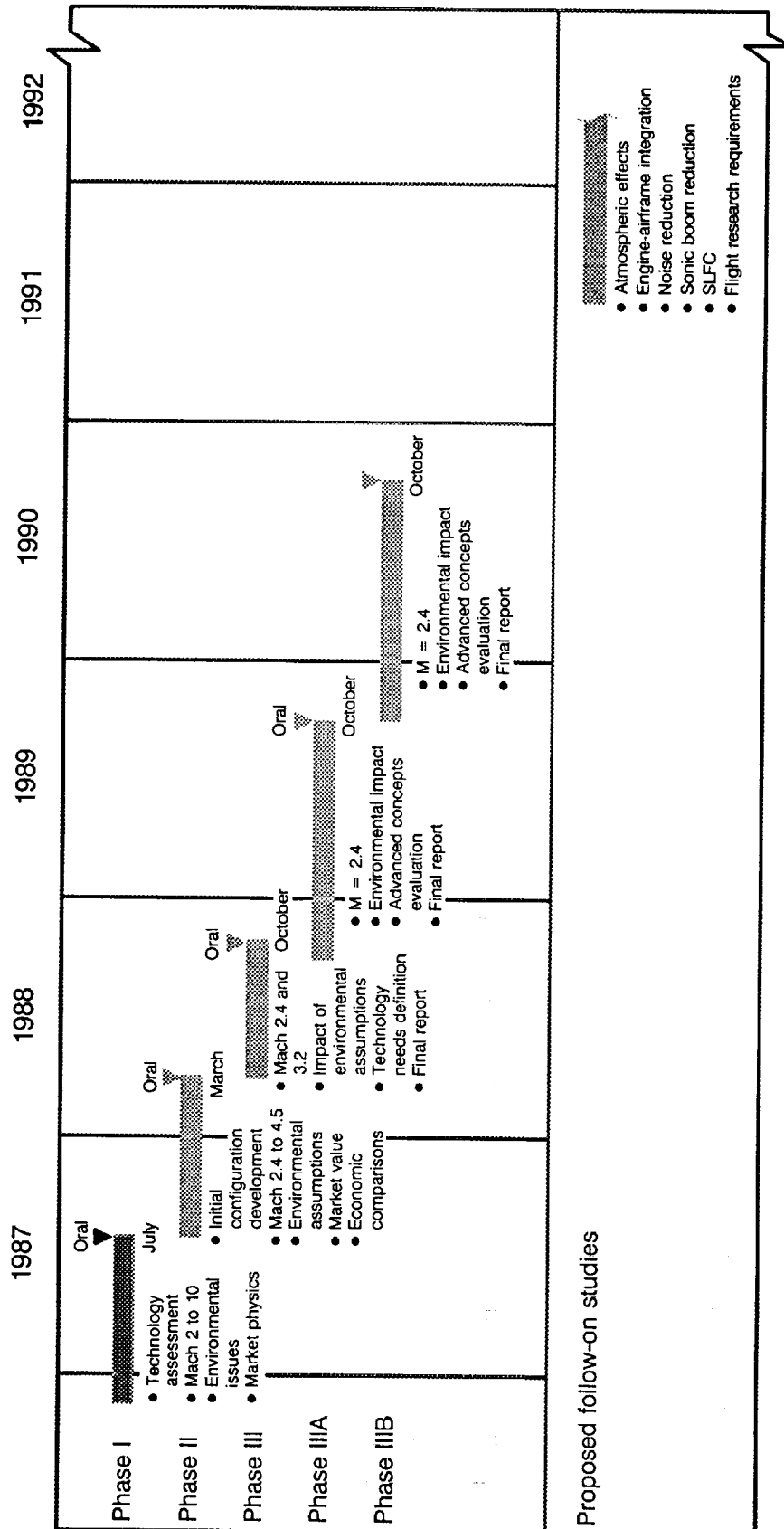
In the later program phases we focused on the lower Mach numbers because they looked most promising for an HSCT.

In this presentation we will summarize for you the highlights of each of these study phases.

We are ready to embark on a 5 year follow-on program of additional NASA/Industry HSR systems studies, to further address and resolve the barrier environmental issues and to advance the relevant high-risk technologies.

I shall briefly discuss the proposed work, as well.

HSCT Airframe Systems Studies



NASA HSCT STUDY - PHASE I

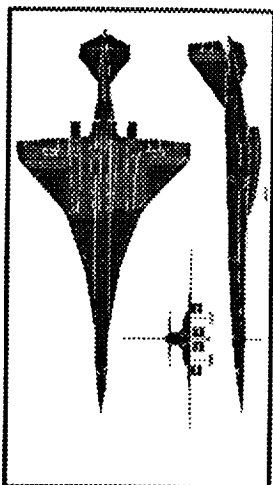
The Phase I objective was to investigate a possible synergism between the National Aerospace Plane and its' technologies and a future HSCT.

The upper Mach number limit for investigation was quickly reduced from Mach 25 to Mach 10. Mach 2.4 was picked as the lower limit. A matrix of concepts was evaluated.

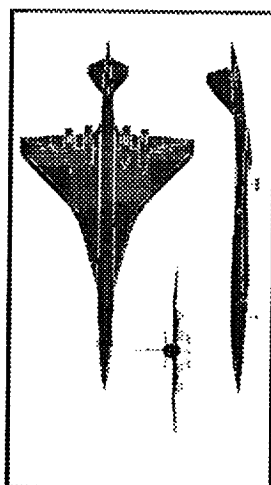
Hydrocarbon was the fuel of choice for the lower Mach number concepts. Cryogenics were the fuels of choice for the higher Mach number concepts.

NASA HSCT Study Phase I

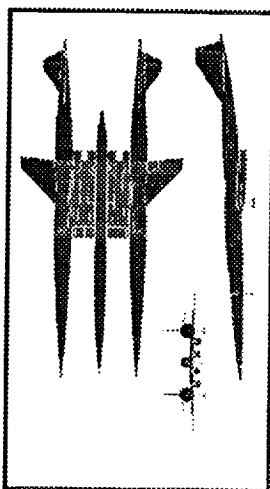
Mach 4.5



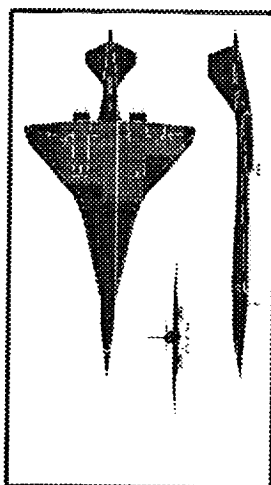
Mach 2.4



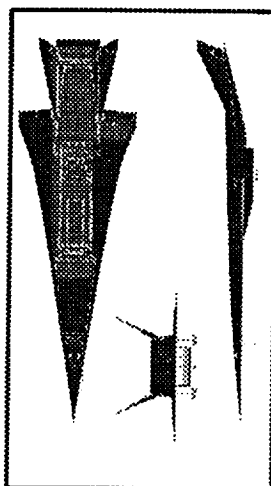
Mach 6.0



Mach 3.2



Mach 10



Hydrocarbon Fuel

Cryogenic Fuel

GROSS WEIGHT VERSUS MACH NUMBER

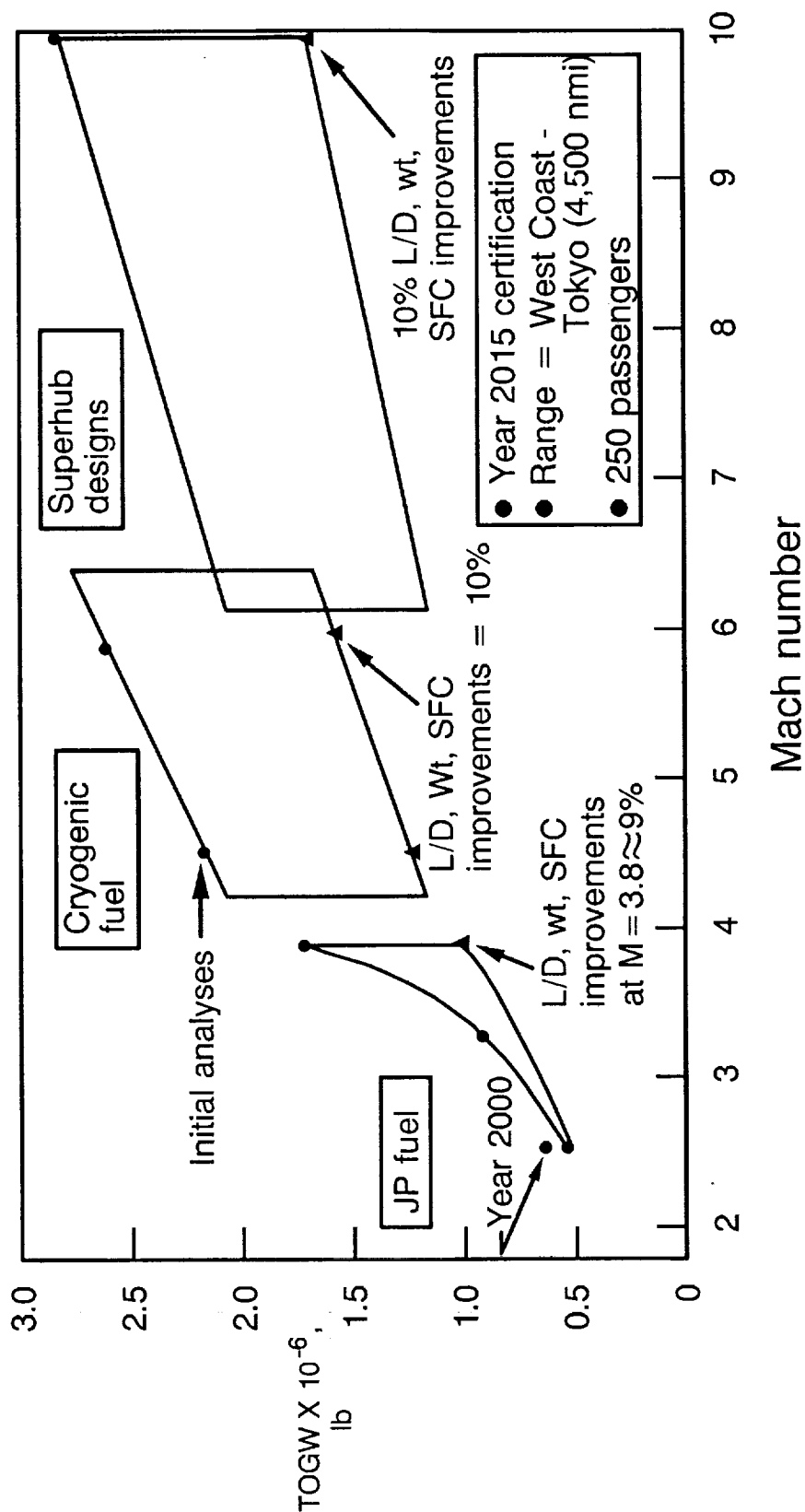
Evaluation of the initial concepts showed this trend in gross weight versus Mach number for vehicles sized to carry 250 passengers over 4,500 mile range.

The upper limit of the band represents year 2015 technology. You can see that any concept above Mach 3.5 exceeds one million pounds in TOGW.

We looked at how much we could reduce TOGW if it were possible to improve by 10%, respectively, aerodynamic lift-to-drag ratio, structural weight and specific fuel consumption. These improvements would reduce TOGW to the lower limit of the band.

Still, any concept above Mach 4 would exceed one million pounds, which we feel to be nearing the limit for commercial airports as we know them.

Gross Weight Versus Mach Number



EFFECT OF INCREASING CRUISE MACH NUMBER ON THE SYSTEM AVERAGE MACH NUMBER

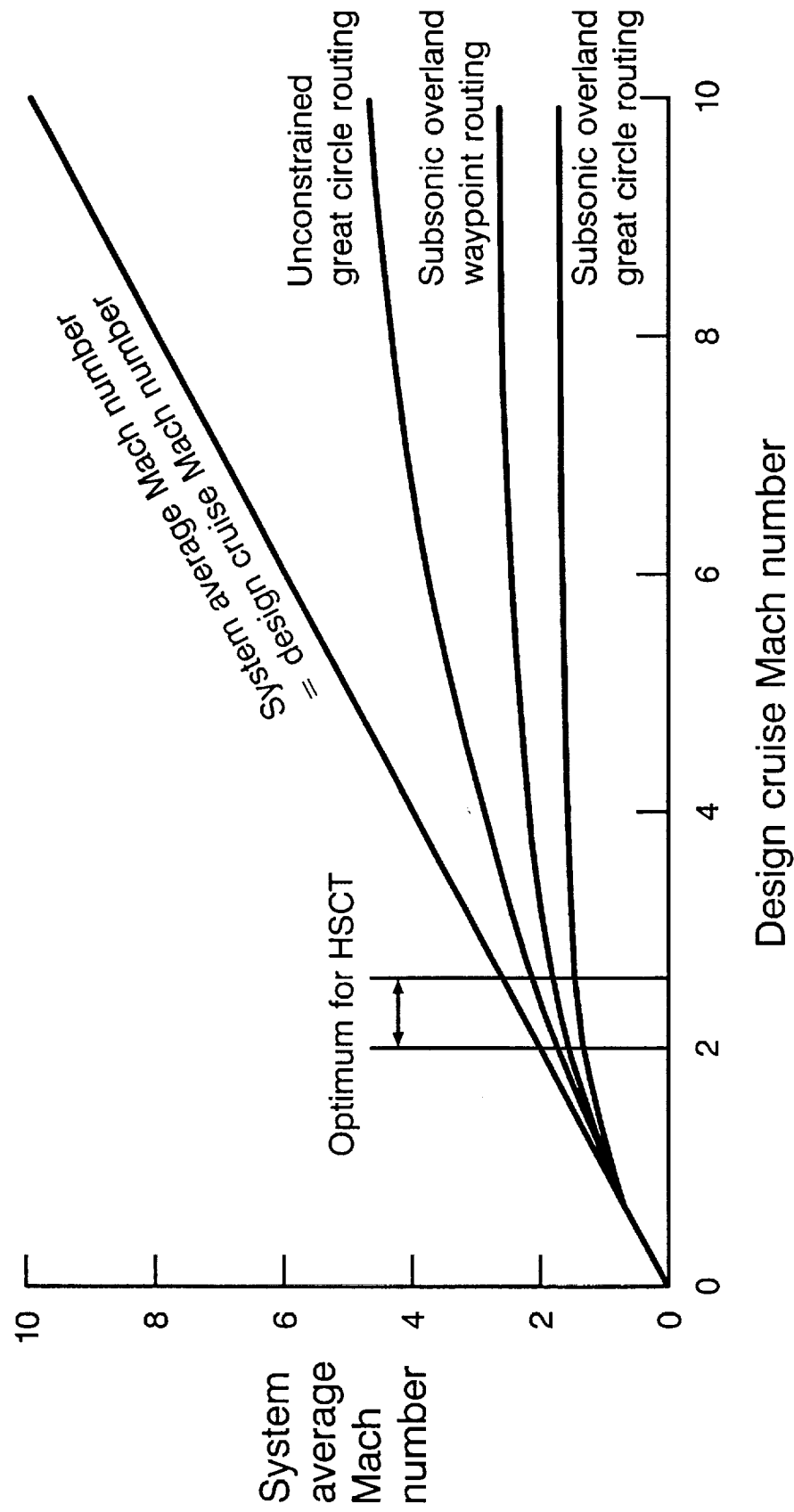
This Figure shows what the system average Mach number would be if you operate a high Mach design on a given airline route system.

As design Mach number increases, the airplane spends more and more time accelerating and decelerating. Which means that even with unconstrained great circle routing the average Mach number is reduced well below the design Mach number.

If you then add the realistic constraints of subsonic overland operation, one hour turn-around time and nighttime curfews, the average Mach number is reduced further. There is an optimum speed for HSCT in the Mach 2 to 3 region. Higher speed results in diminishing or no advantage.

For this reason, and because of the excessive TOGW of the Mach 4.5 plus designs, we focused on the lower Mach range during Phase II studies.

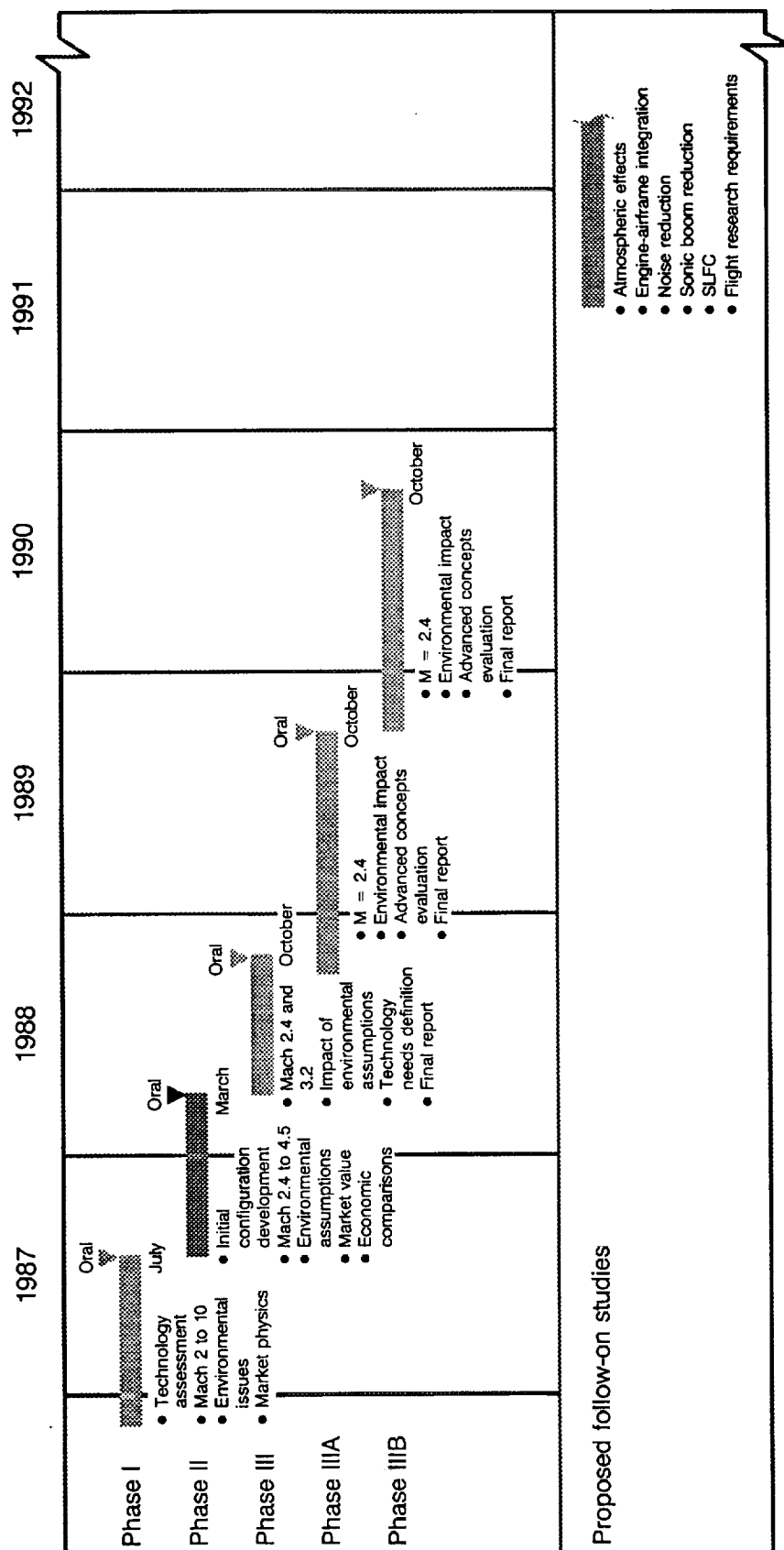
Effect of Increasing Cruise Mach Number on the System Average Mach Number



HSCT AIRFRAME SYSTEMS STUDIES

During Phase II we looked in greater depth at a reduced Mach number range. We looked at a matrix of Mach 2.4 to 4.5 designs, assessed their market value and compared their economics.

HST Airframe Systems Studies



AIRPLANE SIZE PROJECTIONS

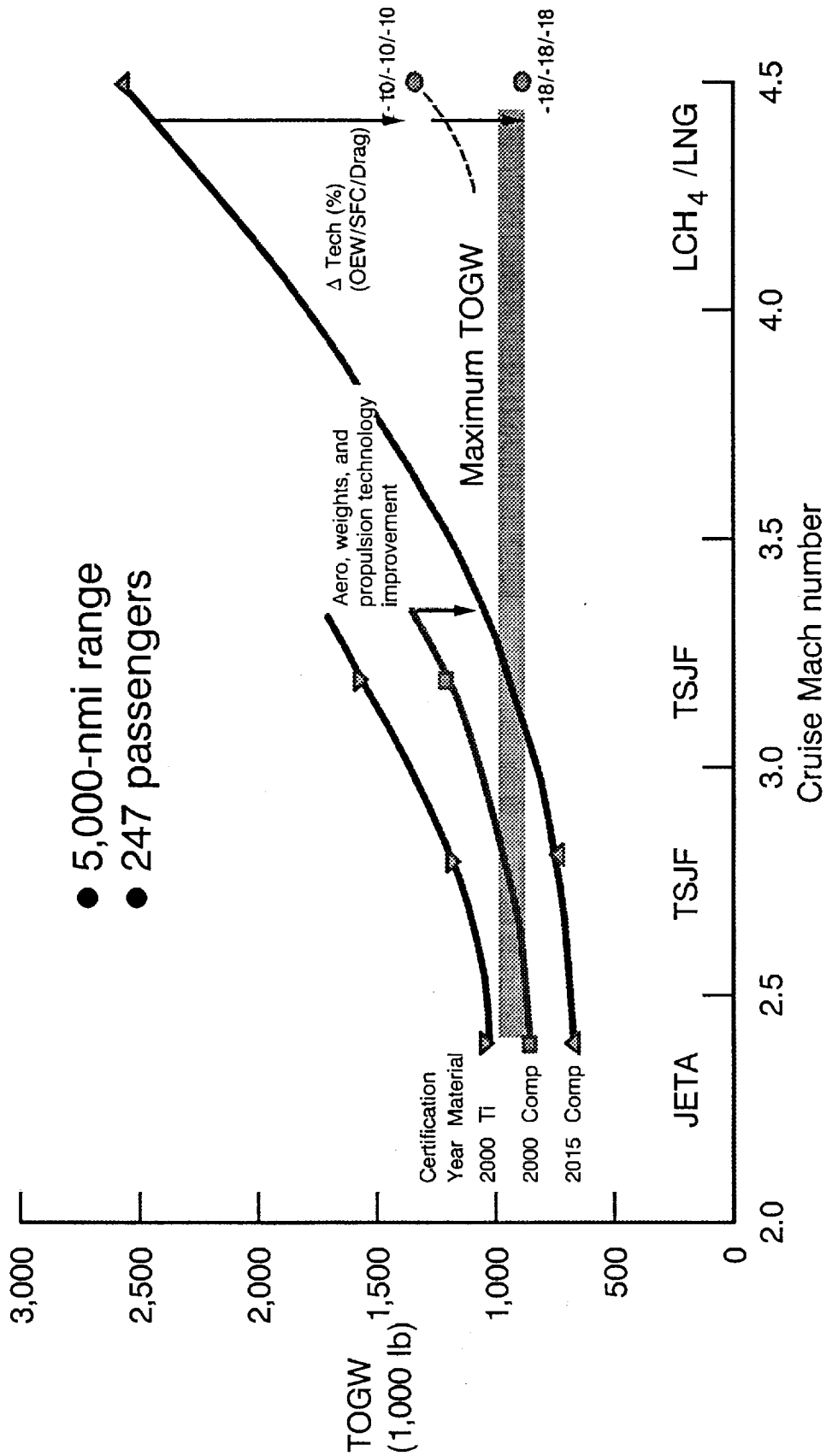
The results are shown here, in terms of TOGW versus cruise Mach number.

Airport handling considerations limit maximum TOGW to about one million pounds. Even with 2015 technology we exceed that limit somewhere between Mach 3 and 3.5. With current technology and with titanium structure there appears to be no feasible solution at all.

For the Mach 4.5 designs we determined that it would take an additional 18% improvement beyond year 2015 technology projections, in drag, structural weight and SFC, respectively, to reduce airplane TOGW below one million pounds.

We do not believe these large improvements are possible. Hence, we focused follow-on work on Mach numbers below 3.2. At these lower speeds we also avoid the need for cryogenic fuels and associated logistics problems. The required thermally stable jet fuels, with temperature limits 100F to 150F above Jet A, are considered a lower risk. They require only minor changes in the refining process.

Airplane Size Projections



PHASE III GOALS

Goals for the Phase III studies, performed during 1988, are summarized here.

Read chart

Phase III Goals

Refine commercial viability studies

- Mach 2.4, 2.8, 3.2
- More indepth design work
- Refined economic analysis

Determine impact of environmental requirements

- Emissions reduction
- Community noise reduction trades
- Low sonic boom design

Define key technology needs

ENVIRONMENTAL GOALS

It will take the combined ingenuity of NASA and Industry to come up with the required technology breakthroughs to meet the tough environmental challenges that are facing us.

We are seeing some promising concepts already, but much more remains to be accomplished.

Environmental Goals

Emissions:

- No significant ozone depletion

Airport noise:

- As quiet as Stage III subsonic airplanes

Sonic boom:

- No perceptible boom over populated areas

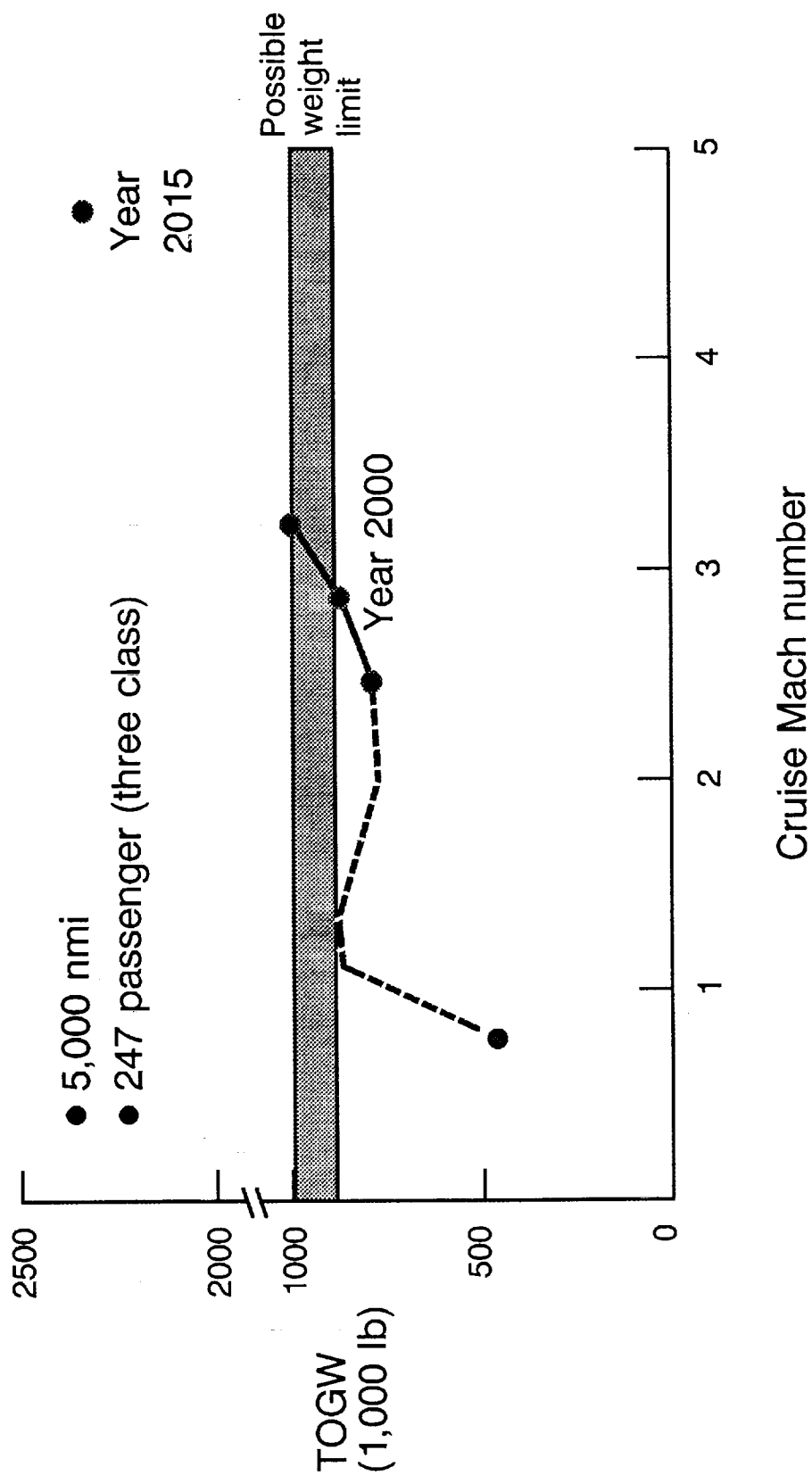
AIRPLANE SIZE PROJECTIONS

In terms of airplane gross weight, it looks like there is a bucket in the curve between Mach 2.0 to 2.4.

TOGW can be as low as 750,000 lb for a 5,000 mile airplane with 250 passengers, provided we achieve the weight savings associated with composite structures' improved specific strength and stiffness.

Based on that weight trend we have focused in on Mach 2.4, with the understanding that we can back off to Mach 2 if we discover any showstoppers.

Airplane Size Projections Composite Structure



IMPACT OF TECHNOLOGY

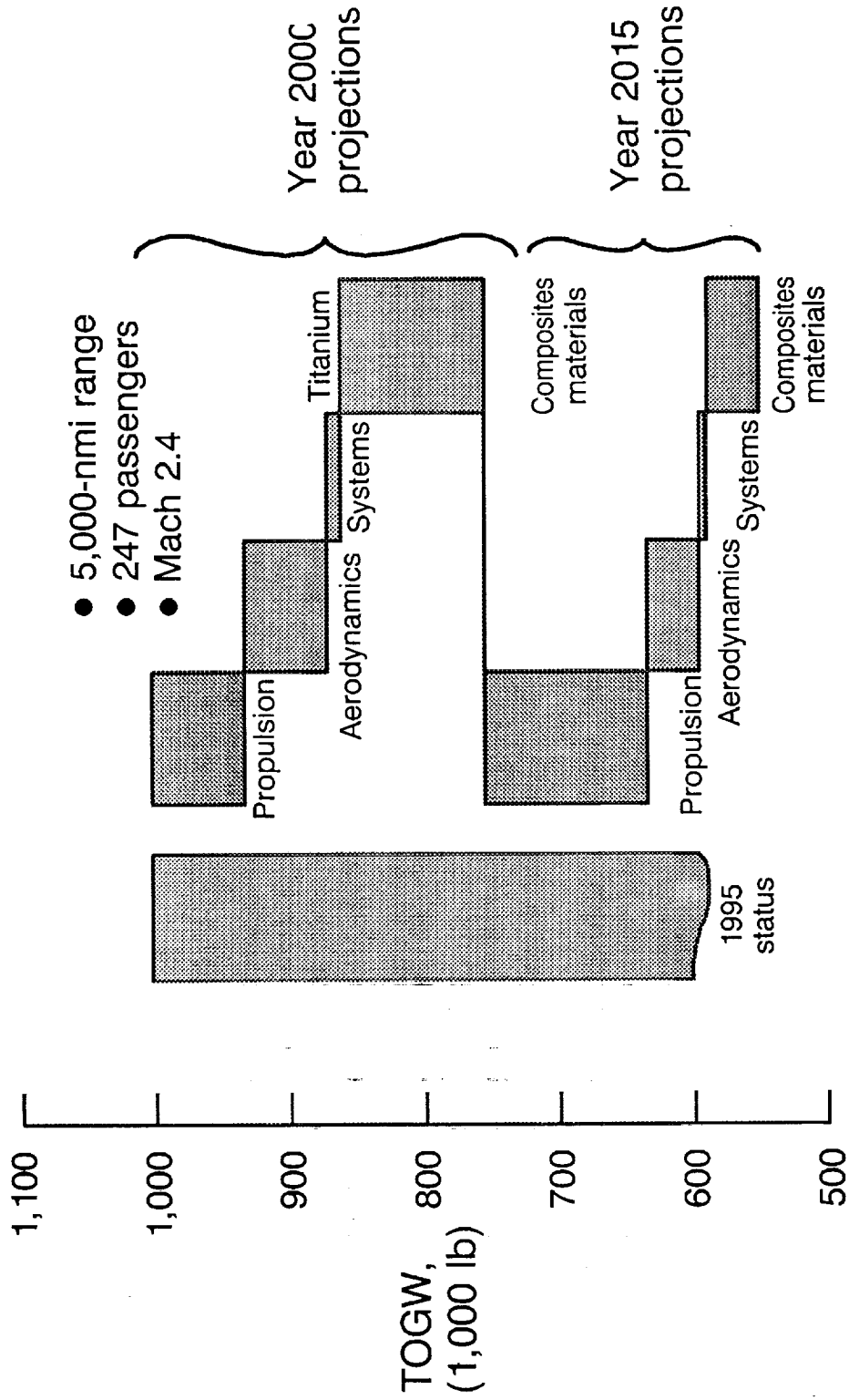
In this Figure we are taking a closer look at the impact of individual technology improvements on TOGW. The data is for the Mach 2.4 airplane with 250 passengers, 5,000 mile range.

The point of departure is the 1995 technology titanium airplane at one Million pounds TOGW.

Incremental improvements are shown for advancing technology by five years in the areas of propulsion (IHPTET technology and a more effective noise suppressor allow us to reduce engine size), aerodynamics, systems (shown here is the impact of active flutter suppression), and big improvements due to changing from titanium structure to composites. As a result of these technology improvements TOGW is reduced to 750,000 lb.

Advancing the technology by another 15 years to 2015, would result in significant further reductions in airplane size, primarily due to improvements in propulsion as projected by the IHPTET program.

Impact of Technology



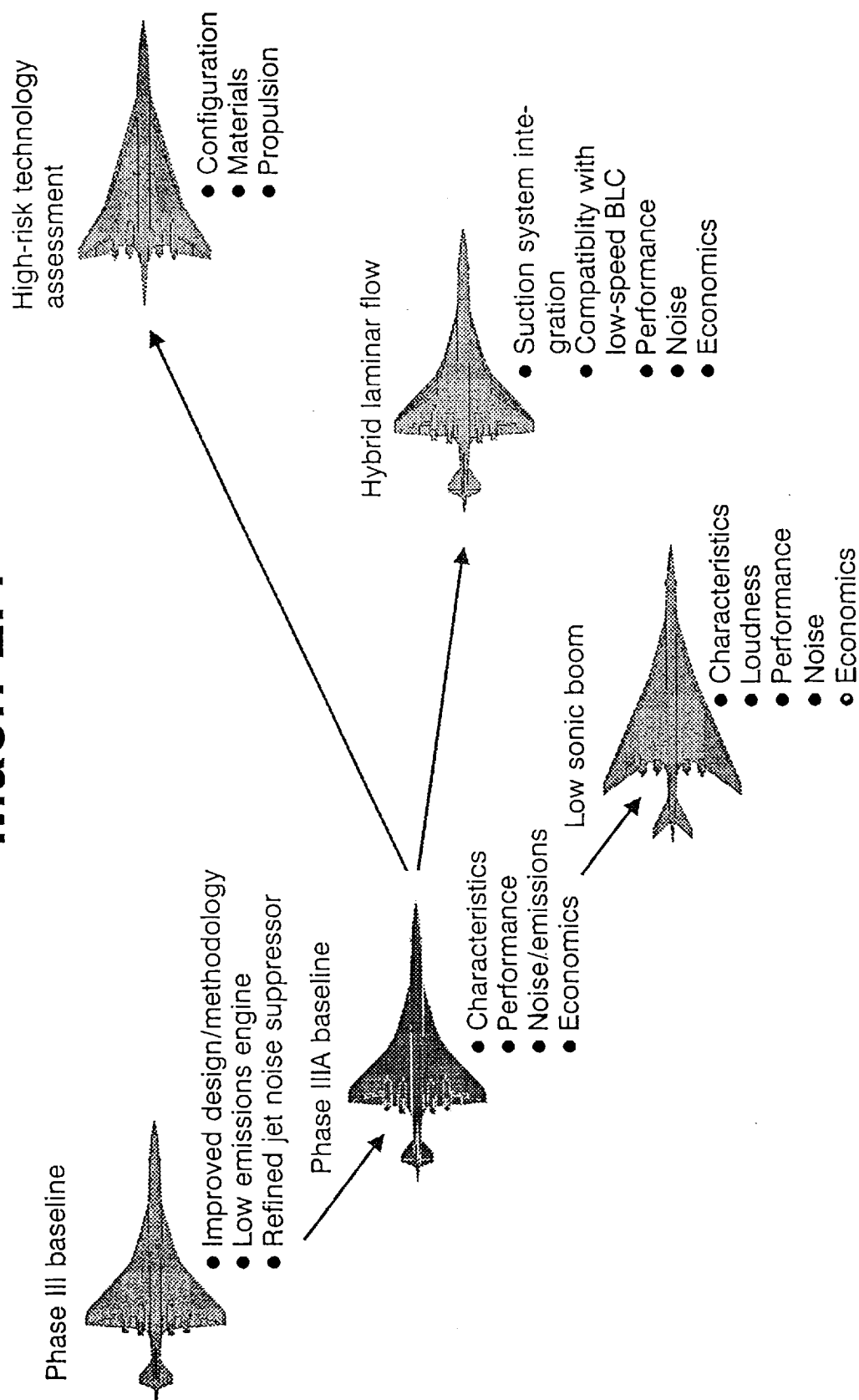
MACH 2.4

Having defined, at the conclusion of Phase III, an improved Mach 2.4 baseline airplane we performed further refinements during Phase IIIA. In addition, we initiated three innovative configuration trade studies that addressed environmental issues:

- 1) a low sonic boom design
- 2) application of laminar flow control to reduce drag, fuel consumption and hence emissions, and
- 3) high-risk technology assessment on an innovative, tailless arrow wing configuration.

I like to point out here that some of the best technology features that were first assessed on this tailless configuration were incorporated later into baselines. That included the extended wing strake and vortex fences, except that we chose to retain an aft horizontal tail to improve the trimmed lift-to-drag ratio of the configuration.

Mach 2.4



REVISED BASELINE

At the conclusion of Phase IIIA, in late 1989, we had thus further reduced the TOGW from 745,000 lb to 679,000 lb, a total savings of 66,000 lb. 40,000 lb was due to resizing the structure in composites. 26,000 lb was due to lower transonic drag.

Changes included a smaller wing and reduced engine size. These changes were biased towards improving economics with a smaller airplane, at the expense of increased noise level. This further emphasizes the need for more effective noise suppressor and improved high-lift aerodynamic efficiency.

Low emissions burner concepts were identified, which came close to meeting our tentative EI goal. The advanced burner had only a small impact on the configuration (+1 to 4% MTOW).

Revised Baseline

- R = 5,000 nmi
- Yr 2,000 cert
- M = 2.4
- Polymeric composites

	Phase III	Phase IIIA	Δ
MTOW-lb	745,000	679,000	- 9%
OEW-lb	323,200	287,000	- 11%
Passengers	247	253	+ 2%
Block fuel-lb	325,100	298,300	- 8%
Noise (ΔEPNdB Stage III)	+ 1.7 - 1.0 - 4.3	+ 2.2 + 2.3 + 1.2	+ 0.5 + 3.3 + 5.5
Emissions EI, lbs/1,000 lb	31	8	- 75%
Sonic boom - psf	2.5	2.5	0 (Supersonic over water only)

AIRPLANE SIZING

Economically, a good indicator of the most viable airplane is the minimum TOGW for a given payload/range and wing/engine combination. That airplane would be located at the "eye of the thumbprint".

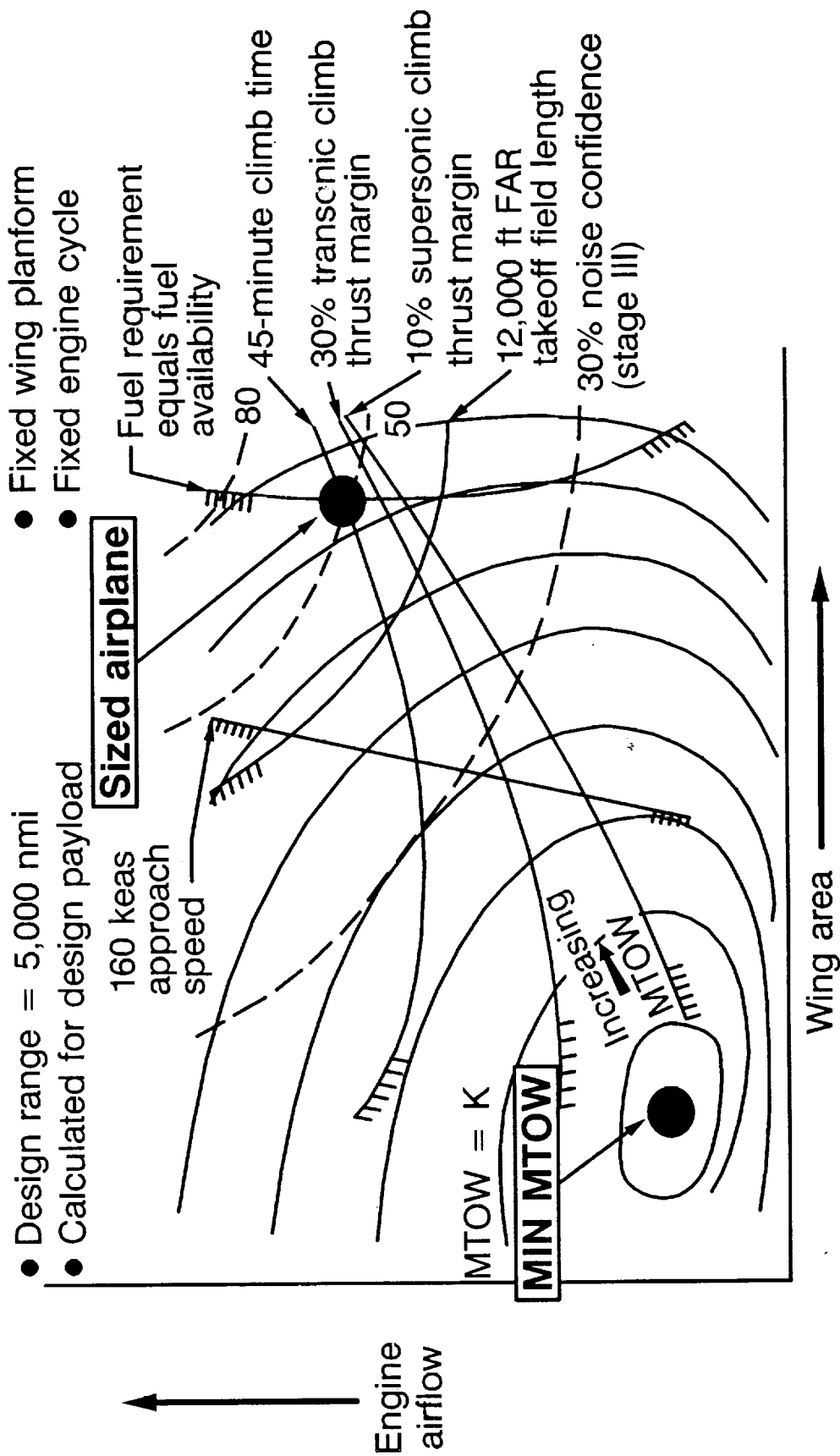
However, practical design constraints, such as required fuel volume and approach speed, tend to require a larger wing area. Other constraints, such as climb thrust margin and TOFL, tend to require a larger engine. As a result the sized airplane tends to be far off the "eye" of the thumbprint and at much higher TOGW.

With the latest baseline airplane update we had reduced the size of the delta wing planform to the point where we had reached the fuel volume constraint. Hence, we increased the size of the inbound wing strake to gain more fuel volume for a given exposed wing area.

Also, we reduced engine size by adding a mini-augmentor.

Both the new smaller wing and the smaller augmented engine moved us closer to the eye of the thumbprint, hence reduced TOGW and improved economics.

Phase IIIA Airplane Sizing



REVISED BASELINE CHARACTERISTICS

Detailed characteristics of the Phase IIIA (1989) baseline and the Phase IIIB (1990) baseline are compared here.

Reduced TOGW, increased payload, reduced engine size all added up to improve economics. The required ticket surcharge was reduced by 40% and is now close to our goal of 10% to 20% relative to a reference subsonic airplane.

TOFL and approach speed increased, but are still within acceptable limits.

Noise levels have increased again. We are heavily relying on innovative proprietary suppressor developments that show promise of providing some of the additional noise reduction. Also, further improvements in high-lift efficiency are needed.

Revised Baseline Characteristics

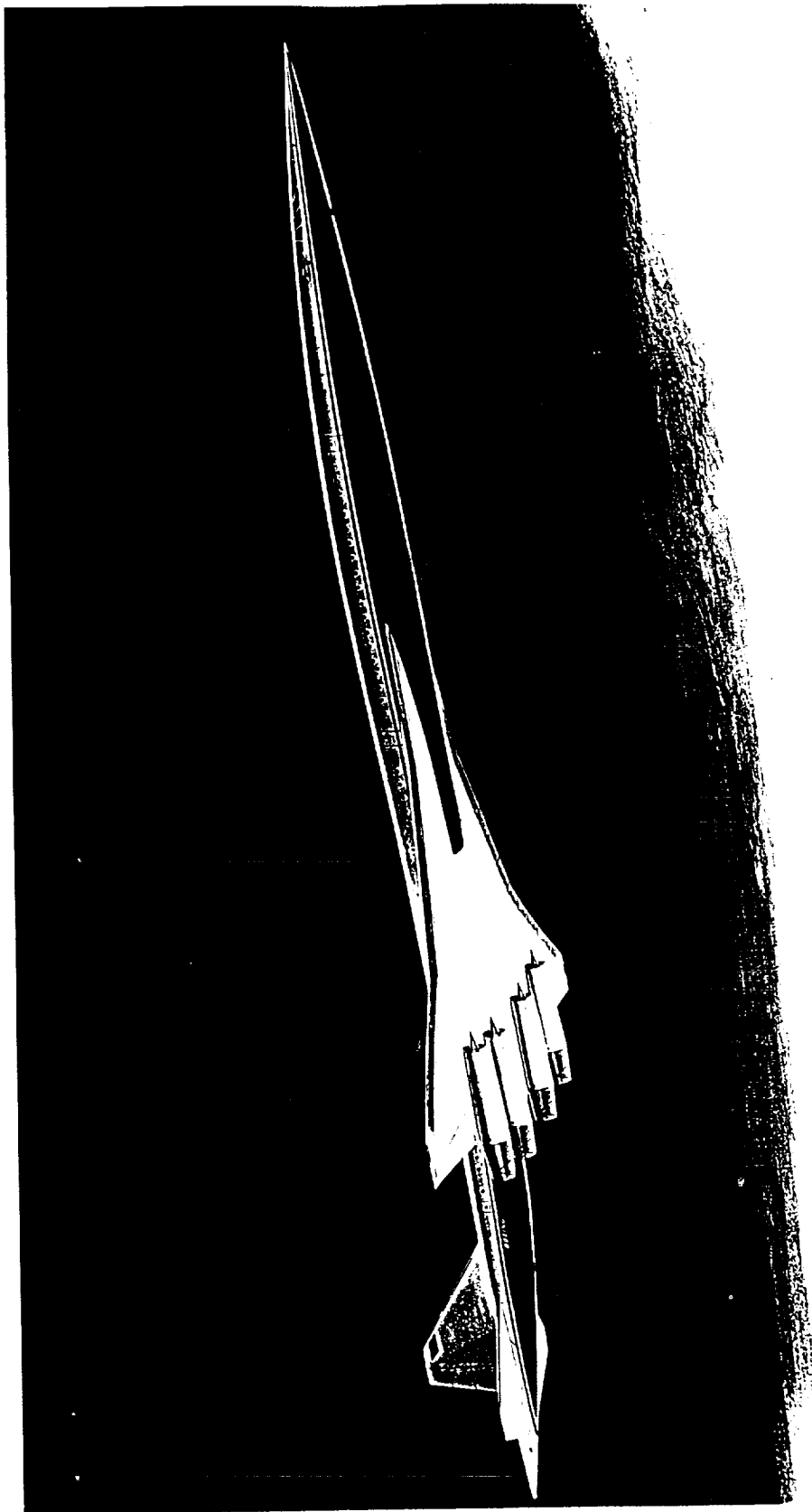
- R = 5,000 nmi • Year 2000 certification • M = 2.4 • Polymeric composites
- Emissions EI = 8 lb/1,000 lb • Sonic boom = 2.5 psf (over water only)

		Phase IIIA	Phase IIIB	Δ
MTOW, lb OEW, lb Passengers Wing area, ft Engine airflow, lb/sec Block fuel, lb/passenger Payload/MTOW, % TOFL, ft Vapp, kt		679,323	667,857	-2%
		286,973	265,117	-8%
		253	279	+10%
		7,970	6,310	-21%
		494	426	-14%
		1,179	1,082	-7%
		7.6	8.8	+16%
		10,200	11,700	+15%
		141	156	+11%
Noise (ΔEPNdB Stage III)	Sideline Community Approach	+2.2 +2.3 -4.3 (+1.2*)	+6.8 +5.7 -3.1	+4.6 +3.4 +1.2
Δ Required revenue factor, % (relative to reference subsonic)		22	13	-40%

* Including turbine noise

Baseline Status - September 1990

- **Economics**
 - Economic viability has improved since Phase IIIA; further improvements needed in configuration, materials, and engines
- **Noise**
 - Noise levels have increased since Phase IIIA; more work required on noise suppressors and high-lift systems to achieve Stage III
- **Emissions**
 - Phase IIIA low-emissions burner retained small impact on configuration. Emissions requirements still not known; no showstoppers in assessments to date



LOW-BOOM TECHNOLOGY STUDY

Supersonic operation overland could have a beneficial impact on fleet economics. The level of sonic boom acceptable to the public is as yet unknown.

A possible range of acceptable sonic boom loudness is thought to be 65 to 72 dBA, based on limited human response studies conducted in the 60's. NASA is currently conducting research to determine this level.

To achieve that level requires a new sonic boom target wave form, which is characterized by a "delayed-ramp shape", in lieu of the familiar N-wave associated with conventional supersonic airplane configurations.

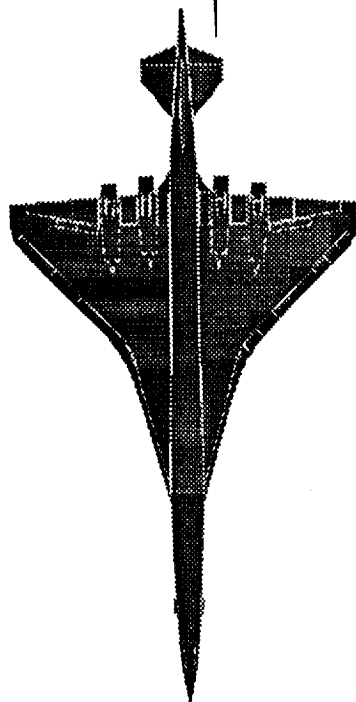
We have designed concepts to these requirements. As shown in the Figure, they incorporate large wings with high sweep-root to tip-to give long lifting length, staggered nacelles, swept tails, long fuselages with contouring for proper aft shock shaping, and longer bulged noses to give the delayed-ramp waveform.

We backed off to Mach 1.7 for low-boom operation. At higher Mach numbers excessive airplane length was required to meet sonic boom targets.



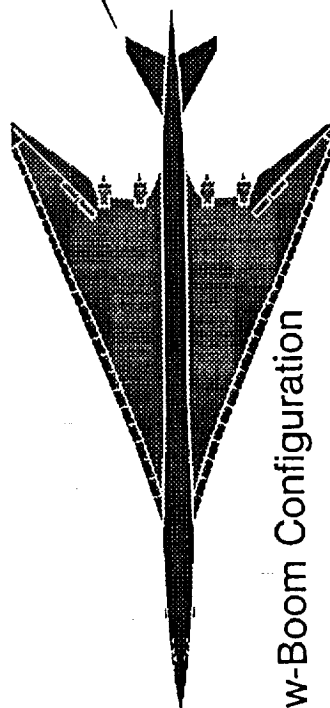
FIGURE 1. Required aircraft length for low-boom operation.

Low-Boom Technology Study



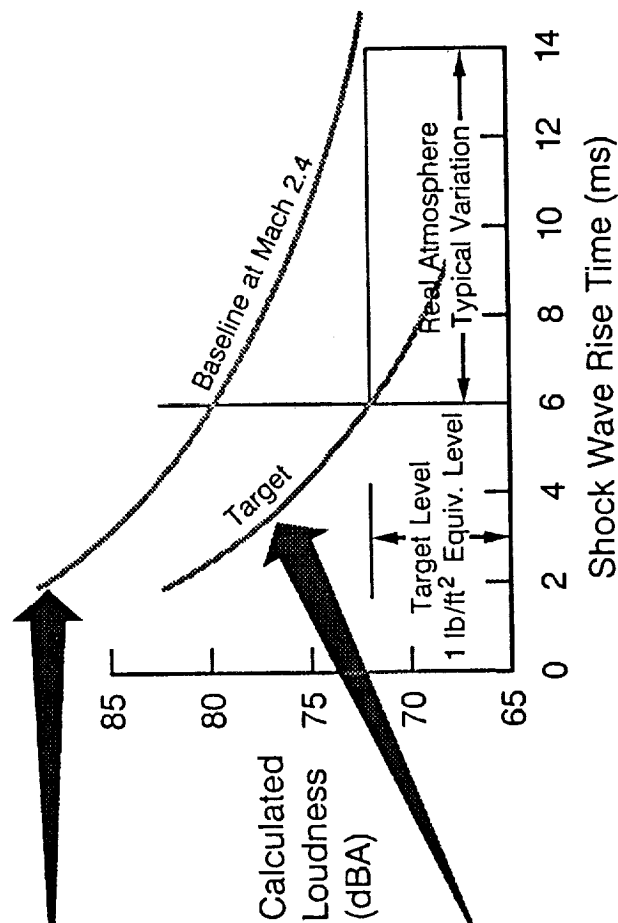
Conventional Configuration

- Mach 0.9 over land
- Mach 2.4 over water



Low-Boom Configuration

- Mach 1.7 over land
- Mach 2.4 over water



SONIC BOOM STUDIES TO DATE

We have completed two iterations of low-boom airplane design and analysis studies to date.

The Phase IIIA configuration exhibited relatively strong shock intensities. The loudness level of 76 dBA exceeded the target of 72.

Because of the larger wing and the more slender configuration, TOGW was up 5% relative to the conventional baseline, OEW was up 14%, community noise was up 2 dB; but improved supersonic efficiency reduced block fuel by 4%.

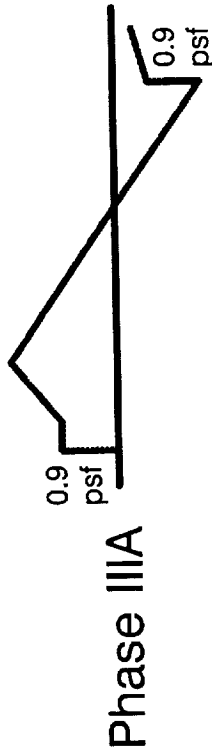
If this airplane could operate overland at Mach 1.7, then the required revenue would be 6% lower than for the baseline. If, on the other hand, the low boom were still unacceptable and the airplane had to operate subsonically, then the required revenue would be 3% higher than the baseline.

The redesigned Phase IIIB low-boom airplane met the loudness target, but lost 15% of its' passenger payload as a result of required fuselage reshaping.

The net effect was an increase in the required revenue to 14% and 25%, respectively, relative to the baseline. Very discouraging results.

We conclude that low-boom airplanes are high-risk at this time. There are still numerous unknowns.

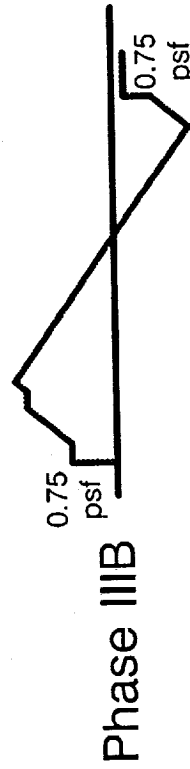
Sonic Boom Studies to Date



+5% MTOW
+2EPNdB
 Δ Revenue requirement = -6% to +3%
76 dBA, target = 72 dBA

+14% OEW
-4% Block fuel

Constant payload



+1% MTOW
-2EPNdB
 Δ Revenue requirement = +14% to +25%
71 dBA, target = 72 dBA

+8% OEW
-1% Block fuel

-15% payload

- Acceptable waveform not known (level and shape)
- Real atmospheric effects not known (design margins necessary)

HLFC APPLICATION TO HSCT

An HSCT has greater sensitivity to aerodynamic drag reduction than its' subsonic counterpart.

Skin friction drag accounts for approximately 40% of the total drag at cruise conditions. In regions where laminar flow is maintained, skin friction drag is reduced by a factor of 8 to 9.

Under NASA/Boeing systems study contracts we have performed extensive HLFC applications studies. We have evolved a laminarization scheme as illustrated in the Figure. The scheme includes suction regions as well as natural laminar flow regions on both the wing upper and lower surfaces.

The aerodynamic benefits include a cruise drag reduction of 8.5%. The suction system can also be used in a suction BLC mode during low speed high-lift conditions to maintain attached flow over the wing

We have studied, in some depth, the implementation of the HLFC system. We have identified significant implementation penalties, as summarized in the Figure. However, the benefits far outweigh the penalties.

Economic benefits are due, primarily, to the reduced fuel consumption of the smaller airplane.

Because of its' high potential we recommend that this high-risk technology be pursued aggressively.

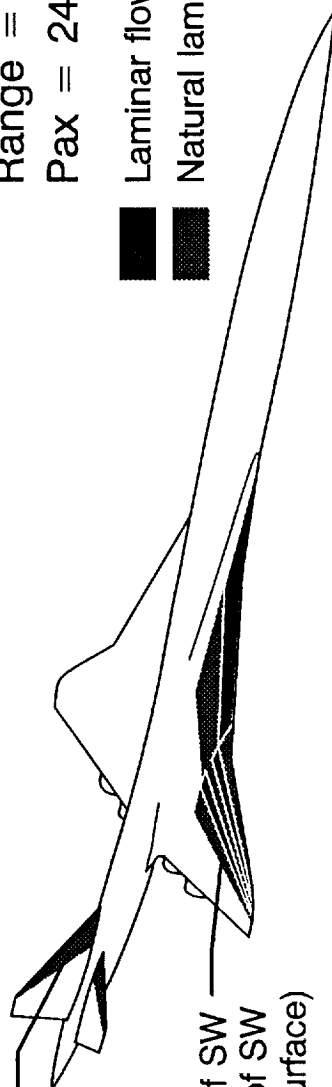
HLFC Application to HSCT

20% NLF
on empennage

$M = 2.4$

Range = 5,000 nmi

Pax = 247



■ Laminar flow with suction
■ Natural laminar flow

Suction over 14% of SW
Laminar over 40% of SW
(upper and lower surface)

Aerodynamic Benefit

- Cruise drag reduction : 8.5%

Implementation Penalties

- System and structural weight increment:
8,000 lb (2.7% of OEW)
- System fuel displacement:
38,000 lb (10.3% of available fuel volume)
- Engine power extraction:
1,185 HP (0.4% TSFC penalty)
- Suction air momentum drag:
0.45 counts (0.4% of cruise drag)

Performance Benefits

MTOW reduction	6.5%
OEW reduction	2.7%
Engine size reduction	9.9%
Block fuel reduction	11.1%

Economic Benefit

18% reduction in surcharge required
for 12% ROI

CONCLUSIONS

The conclusions from the NASA systems studies to date are:

Projected HSCT economics have improved. Required revenue is 10 to 15% above the reference subsonic.

Major issues and technology development needs remain:

We do not meet stage III noise goals with small engines using augmentors. The effectiveness of noise suppressors needs to be improved. Results of proprietary developments in the noise suppressor area look promising.

Low emissions burner concepts have only a small adverse impact on the airplane. However, emissions requirements are still not known. There have been no show stoppers in assessments to date.

The final engine cycle needs to be defined. We need the performance level projected by the IHPTET program for year 2000 technology.

Low cost durable composite materials with improved specific strength and stiffness are crucial to meeting structural weight goals.

Improved high-lift systems ,that maintain attached flow over the wing during takeoff and climbout are needed to contribute to noise reduction.

In addition, we have identified large payoff potential for high-risk technologies, such as laminar flow control.

Conclusions

- Economic viability has improved since Phase III. Improvements still needed, but with projected technology looks promising

Major issues:

- Noise suppression
- Emissions requirements
- Engines
- Materials development
- High-lift systems

- Potential large payoff for high-risk technology for post year 2000 HSCT

Key elements

- Advanced aerodynamics, stability and control, aeroelastics
- Advanced engine technology
- Advanced materials
- Supersonic laminar flow control
- Low-boom technology

PROPOSED HSR SYSTEMS STUDIES' 1991 - '95

We are currently finalizing plans with NASA for the follow-on airplane systems studies.

We have proposed to work in six areas; emphasizing the environmental issues technologies. The proposed distribution of effort during 1991 is indicated:

Further study of atmospheric effects. - Here we expect to support NASA's atmospheric modelling studies by developing detailed emissions scenarios for projected HSCT and subsonic fleets.

Engine-airframe integration. - Here we expect to continue to take part in designing and selecting candidate engines from NASA Lewis and the engine manufacturers and evaluating them on our airplanes.

Noise reduction and laminar flow control. - We believe these are the most important areas to work now; the former because of the need for success, the latter because of its' high potential for improving economics.

Sonic boom reduction. - We need to continue some effort in this area in spite of the discouraging results to date. Also important to understand boom physics, e.g., secondary booms.

Flight Research Requirements. - Here we propose to look at what flight research will be required to answer important questions on emissions and to validate key technologies. We will evaluate potential aircraft to be used for the research, and identify cost-effective approaches.

Proposed HSR Systems Studies, 1991-95

1991 effort

- | | |
|-----------------------------------|-----|
| ● Atmospheric effects and impact | 9% |
| ● Engine-airframe integration | 9% |
| ● Noise reduction | 27% |
| ● Sonic boom reduction | 5% |
| ● Supersonic laminar flow control | 32% |
| ● Flight research requirements | 18% |

SYSTEMS STUDIES PERSPECTIVE

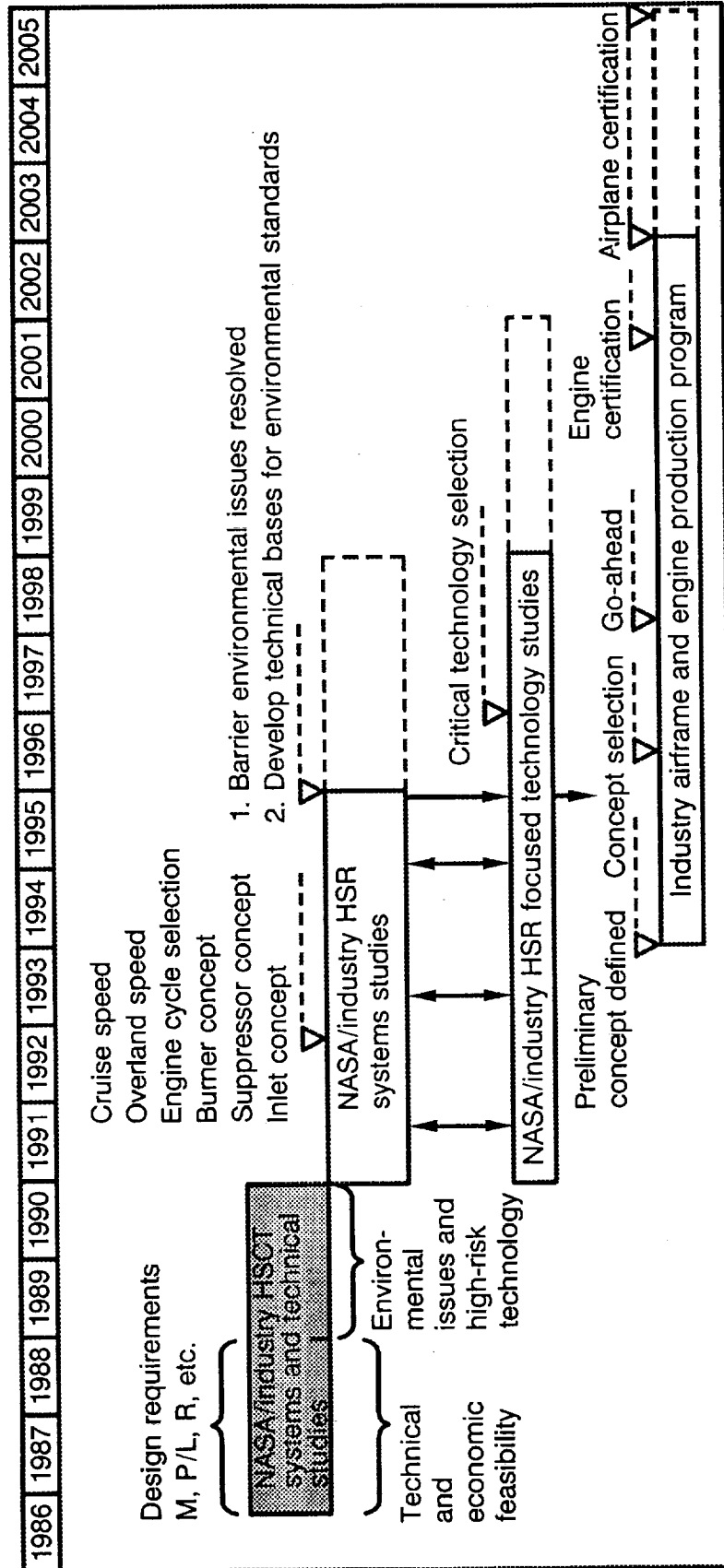
In perspective, the NASA/Industry systems studies are an essential element of the NASA High Speed Research Program.

The evaluation of environmental issues and technological solutions on practical HSCT concepts puts us in a position to make realistic projections of the environmental impact, of the economic viability and the technology needs for the HSCT. In this way, the systems studies provide guidance for the needed technology developments that have to take place in the HSR Phase II.

Only with that guidance can the objectives of Phase II be met; to develop and verify in cooperation with US Industry, the critical technologies for economic viability.

The development and verification of the critical technologies must have been completed before a production program go-ahead can occur.

HSR Systems Studies Perspective



1991 HSCT BUDGET BREAKDOWN

In addition to the NASA-funded research there is now a very significant Boeing-funded HSCT program. It started in 1988 in response to the encouraging results shown by the NASA-funded studies of environmental, technical and economic viability of an HSCT.

Currently, Boeing funding of internal HSCT studies is expanding to build a core HSCT team for preliminary design and technology development.

In 1991, we have approximately 150 engineers working on HSCT. The figure shows the distribution of effort among the three key areas of Technology and Test, Design Development and Manufacturing Research and Development (MR&D).

67% of the effort is focused on technology developments and test in the critical areas of aerodynamics, structures, propulsion and noise.

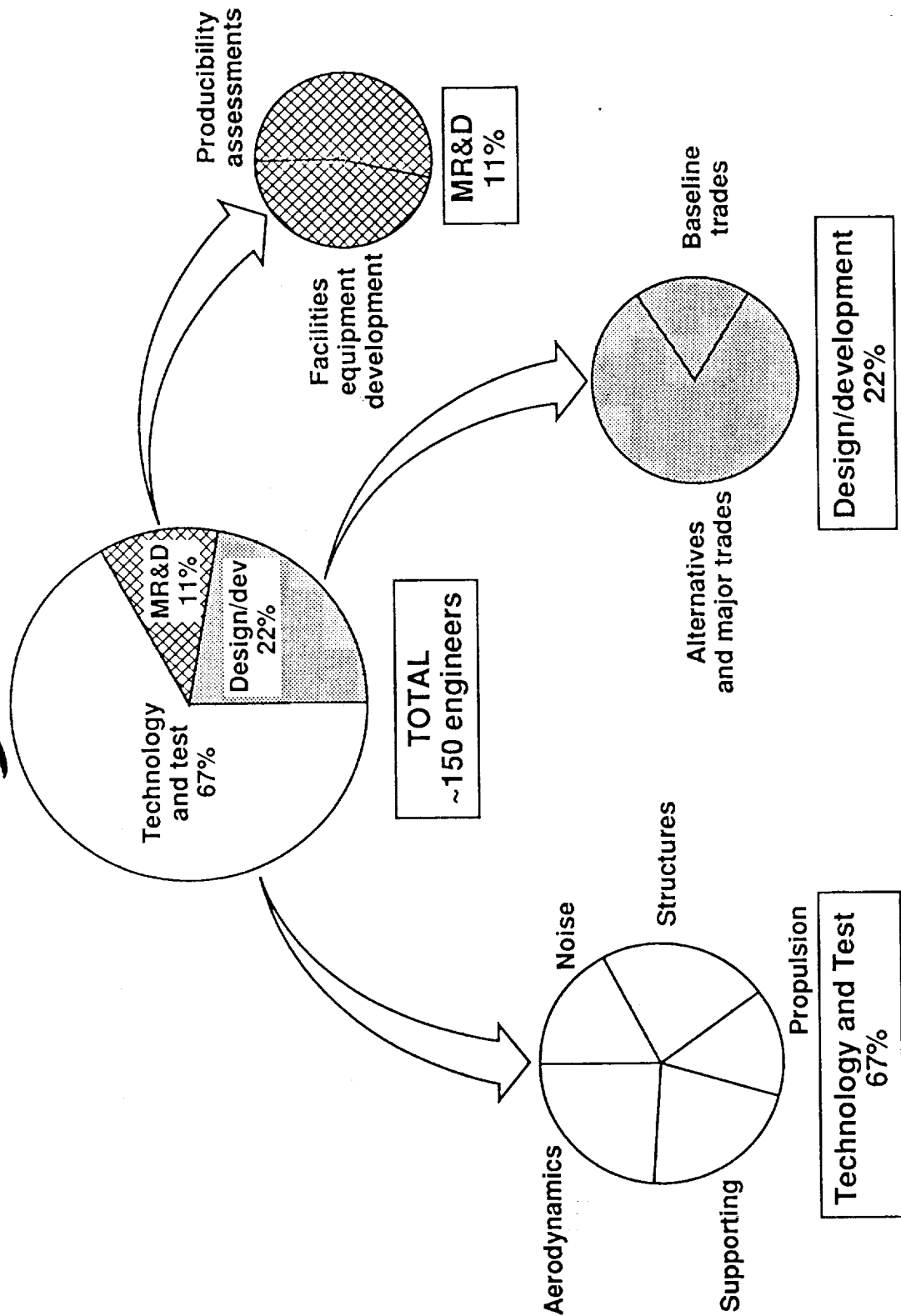
22% of the effort is directed towards developing a baseline airplane and conducting trade studies.

11% of the effort is on MR&D, to answer the question on how we would produce an HSCT of composite structure and at a low cost.

Large increases in on-year funding are planned.

1991 HSCT Budget Breakdown

Boeing 127d



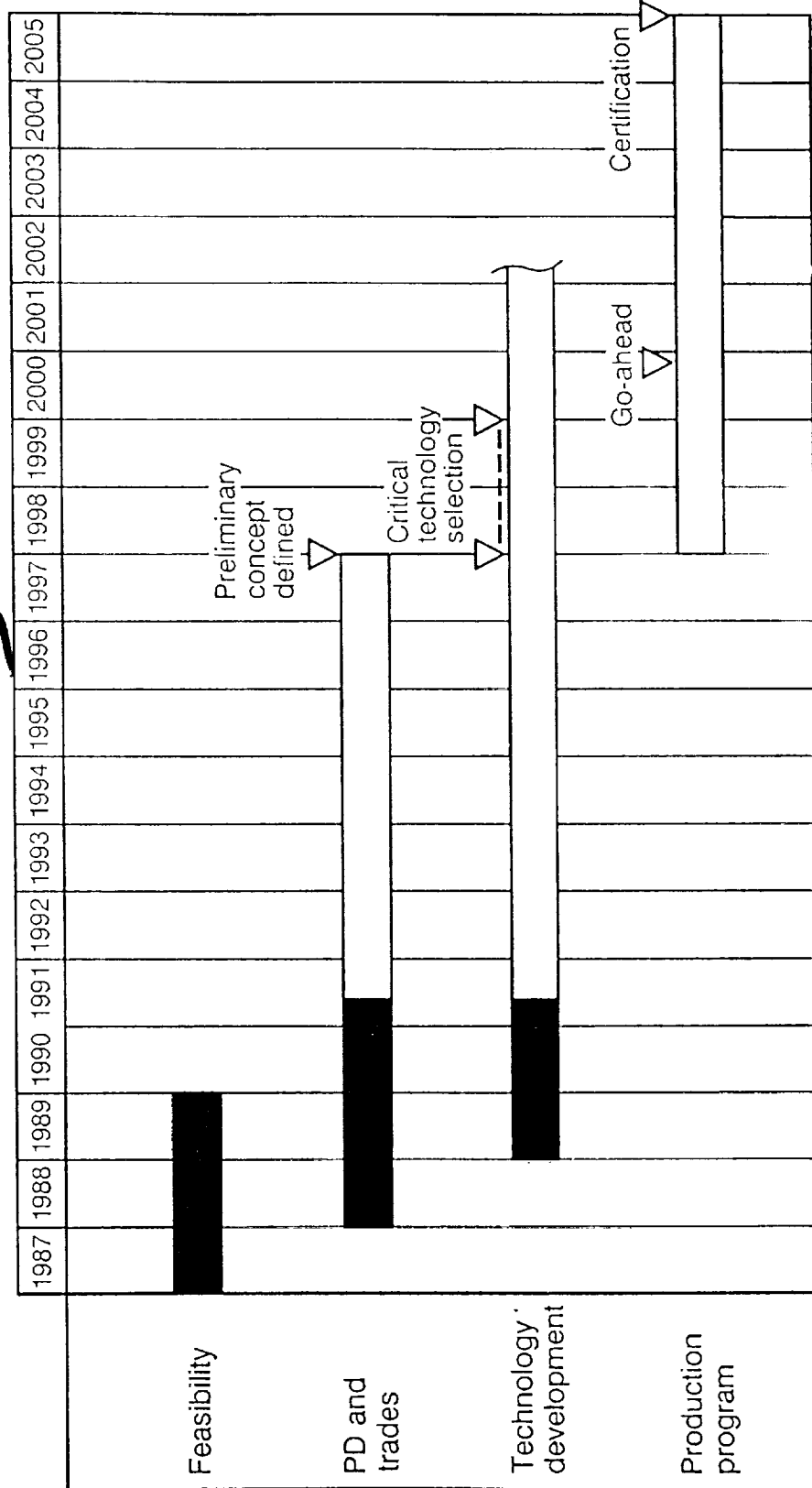
HSCT PLANNING SCHEDULE

The planned increases in funding are aimed at providing the technology and design information necessary for certification of an HSCT in the year 2005.

To meet that date would require the definition of a preliminary concept by 1997, selection of the critical technology by 1999; and a production program go-ahead in the year 2000 - nine years from today.

HSCT Planning Schedule

Boeing



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Session II. Airframe Systems Studies

Douglas Aircraft HSCT--Status and Future Research Needs
H. Robert Welge, Douglas Aircraft Company

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SESSION #2

DOUGLAS AIRCRAFT HSCT
STATUS & FUTURE RESEARCH NEEDS

H. R. WELGE

DOUGLAS AIRCRAFT CO

MCDONNELL DOUGLAS CORP.

FIRST ANNUAL HIGH-SPEED RESEARCH WORKSHOP
WILLIAMSBURG, VIRGINIA
14-16 MAY 1991

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MDC HSCT ENGINEERING SUMMARY

Current activities on the HSCT at Douglas Aircraft are focused on baseline vehicle development at Mach 1.6 and 2.4. Parallel design activities incorporating the latest technologies in structures/materials, propulsion/noise and aerodynamics are also being conducted and incorporated into the baseline to establish performance, economic viability and environmental compliance. Studies are also being conducted to establish the feasibility of incorporating laminar flow control and minimized sonic boom concepts into the baseline. A decision point on these last two technologies is targeted prior to the start of the NASA HSR Phase II program in 1993. The activities summarized in Figure 1.

All actions are focused on the timely initiation of the NASA HSR Phase II program in 1993.

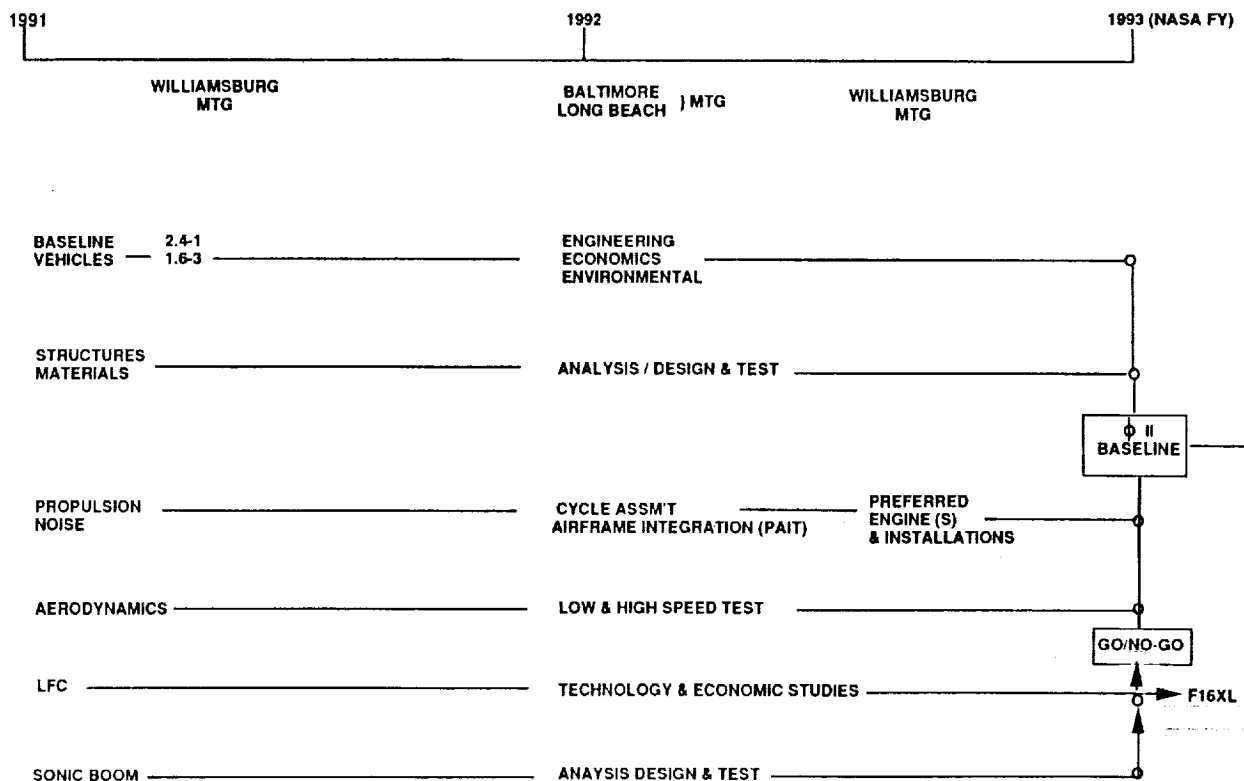


Figure 1

PASSENGER AIRCRAFT
CAPACITY/SUPPLY FORECAST

The available passenger traffic growth through the year 2000 is shown in Figure 2. The retirement of the current fleet and current new orders do not meet the projected demand. The short fall will be filled by HSCT and new subsonic aircraft. HSCT market capture and world fleet split between supersonic and subsonic aircraft will depend on HSCT's operating economics and on the level of fare premium that may be charged to it's passengers.

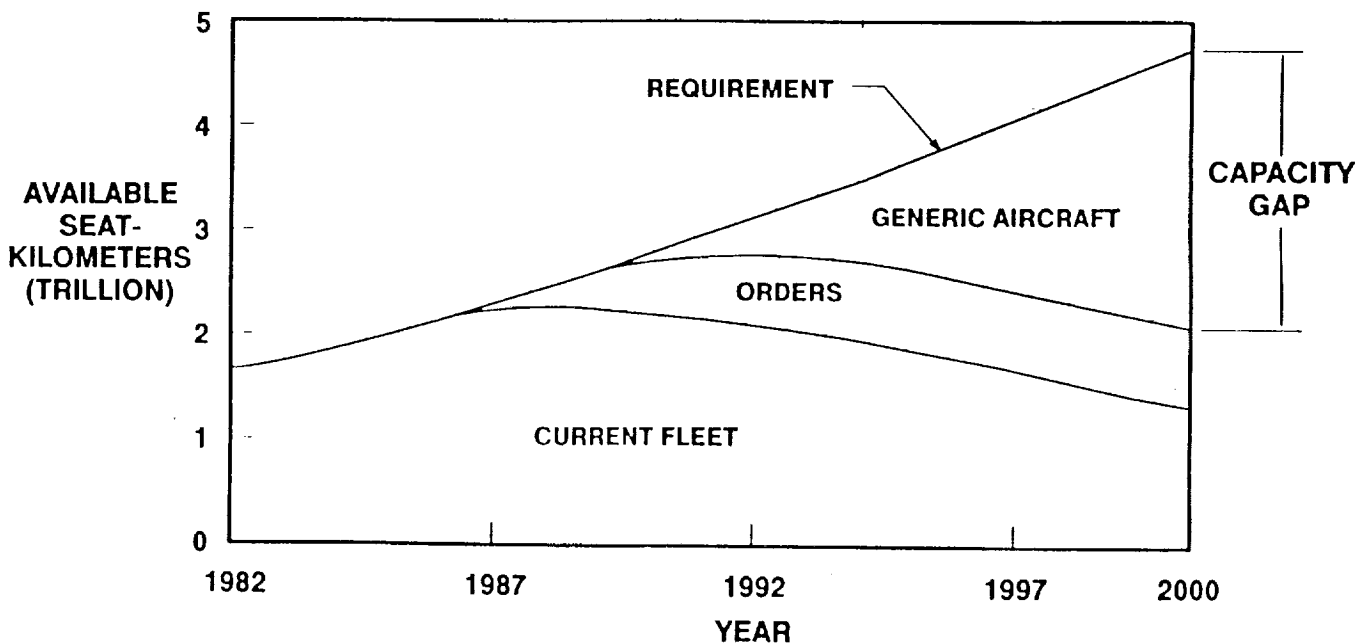


Figure 2

HSCT FLEET PROJECTIONS BASED ON TRAFFIC DEMAND

Based on traffic demands, supersonic fleet projections for Mach 2.2 may exceed 3000 aircraft by year 2030. These fleet projections show a substantial decline as fare premium levels increase. As fare premium levels get higher, the supersonic fleet size may fall short of the commercially viable quantity that attracts the aircraft manufacturers to assume the financial risk of launching HSCT.

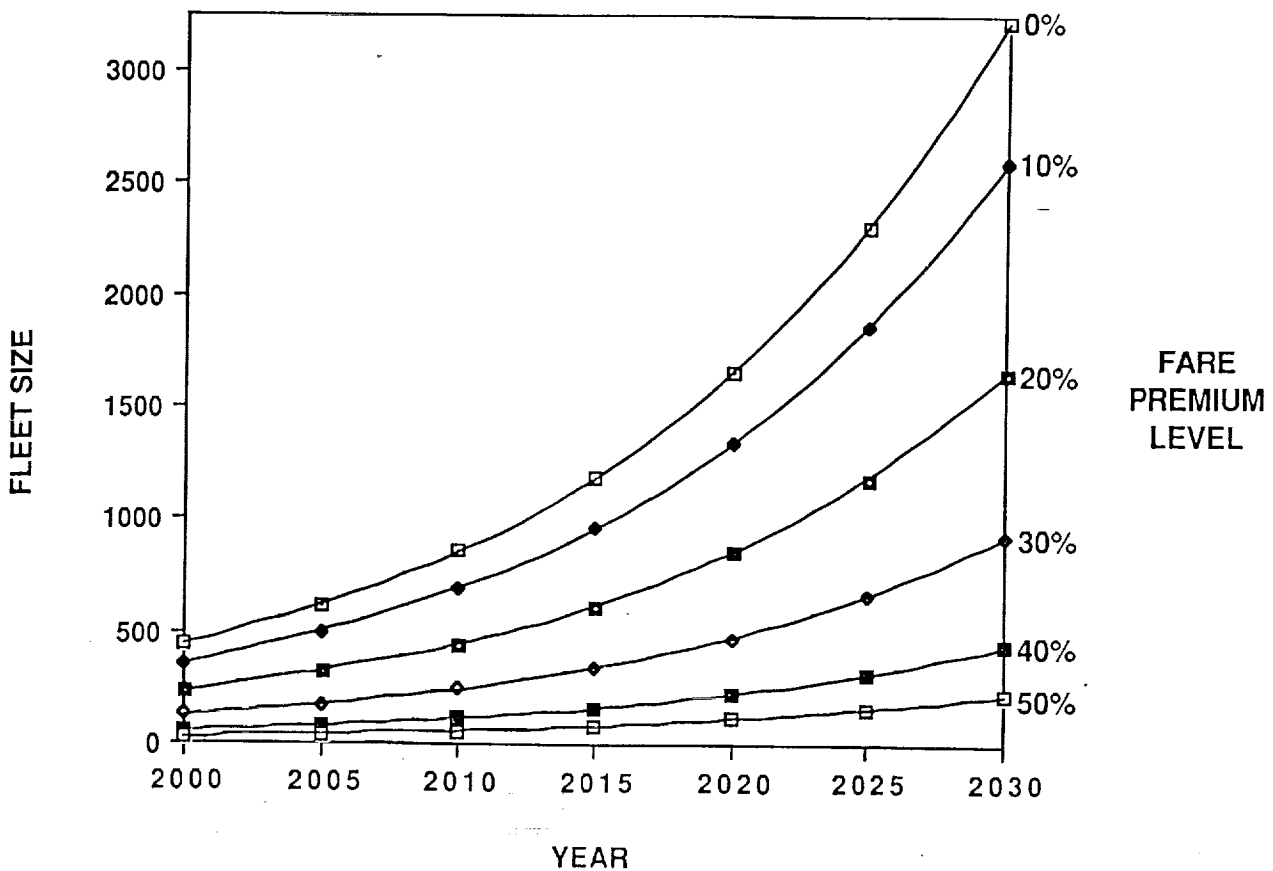


Figure 3

DESIGN FEATURES AND KEY TECHNOLOGIES
FOR OPERATIONAL AND ECONOMIC VIABILITY

The DAC HSCT features numerous advanced technology features as illustrated in Figure 4. Highlights include synthetic visions for the pilot, a fly-by-lite/power-by-wire flight control system, lightweight advanced structural materials, high-lift devices, high airflow augmentation engine nozzle ejectors for Stage 3 noise compliance, and conventional Jet-A fuel.

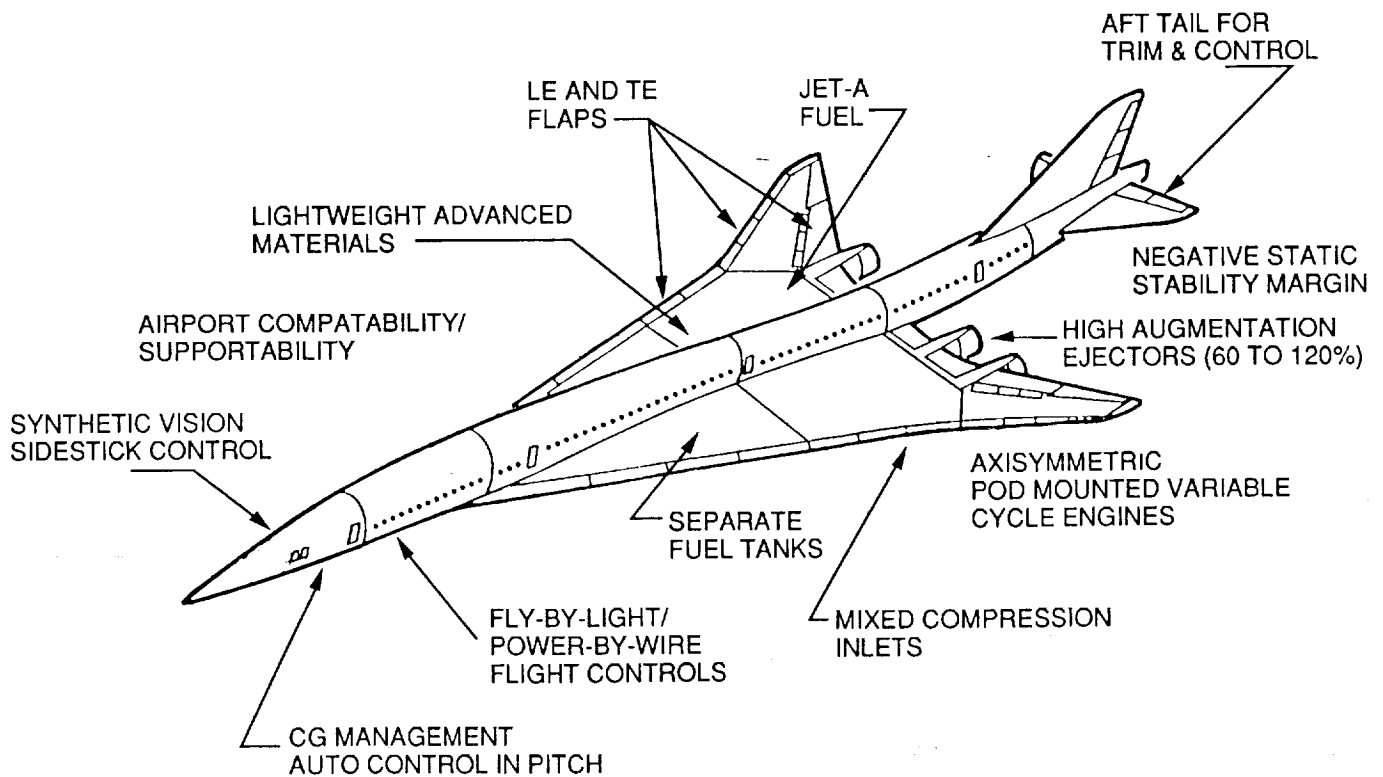


Figure 4

CURRENT PERFORMANCE STATUS

The Mach 1.6 and 2.4 vehicle performance is summarized on Figure 5. The performance shown below is currently based on lightweight airframe materials without cost considerations. DAC trade studies discussed in Session 11 and summarized later in this presentation describe ongoing studies of the structural/material concepts. The selected mission is based on a fleet average basis using 250 city pairs and reasonable re-routing.

- o 5500 NM RANGE / 25% SUBSONIC OVERLAND
- o 300 SEATS
- o 10,600 FT TOFL
- o LIGHT WEIGHT AIRFRAME MATERIALS (AIMMC)
- o TURBINE BYPASS ENGINE CYCLE

	MACH 1.6	MACH 2.4
MTOGW (lb)	725,000	760,000
OEW (lb)	224,000	249,000
BLOCK FUEL (lb)	360,000	372,000
WING AREA (ft ²)	9,300	11,500
THRUST (SLS lb/Eng)	51,500	54,500

Figure 5

MACH 1.6 BASELINE

The Mach 1.6 aircraft planform and major dimensions are shown on Figure 6.

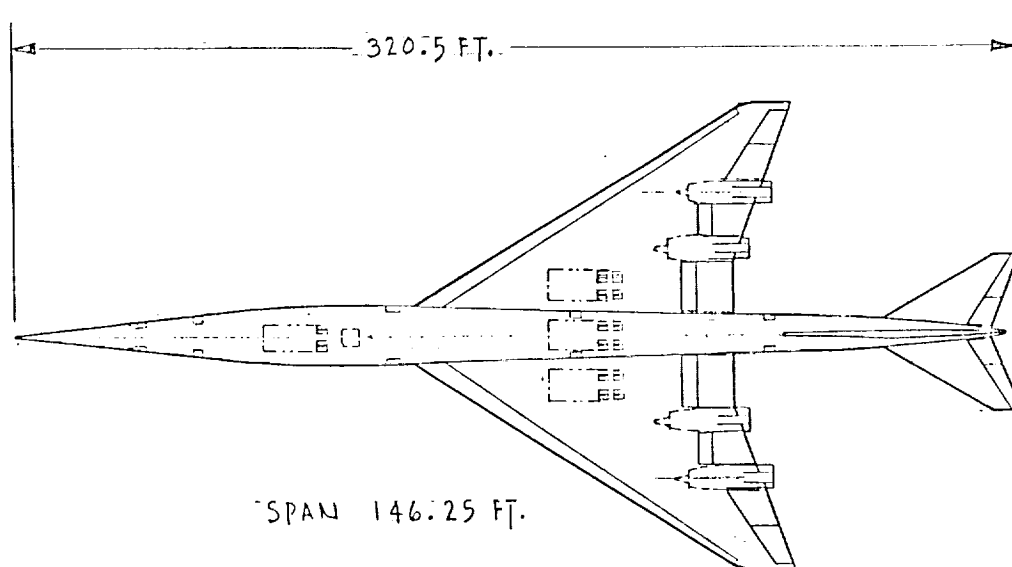


Figure 6

MACH 2.4 BASELINE

The Mach 2.4 baseline planform and major dimensions are shown in Figure 7.

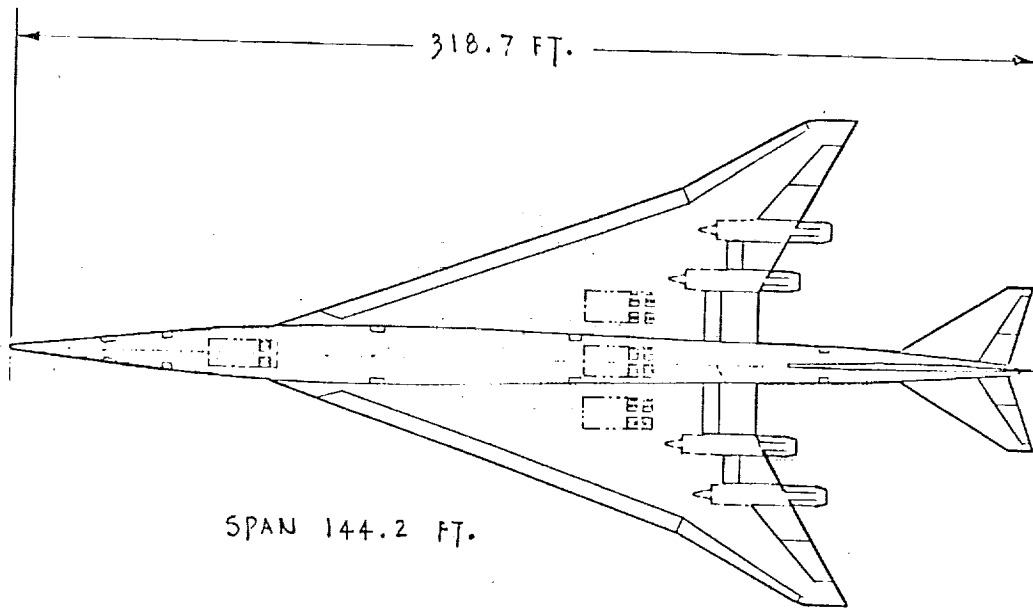


Figure 7

ENVIRONMENTAL TOPICS TO BE DISCUSSED

The status in the three areas shown in Figure 8 will be discussed.

- 1) ATMOSPHERIC EMISSIONS
- 2) JET NOISE
- 3) SONIC BOOM

Figure 8

TOTAL CHANGE IN COLUMN OZONE CONCENTRATION

The results of a parametric analysis conducted to determine the total column change in ozone as a function of mean cruise altitude/cruise Mach number and NOx emissions is shown in Figure 9. Superimposed on this parametric analysis are the emissions for a two levels of annual-seat-miles (ASM) and their corresponding fleet size.

It is generally agreed within the industry that a total ozone column change of more than 1 percent would not meet the environmental acceptance goal. With this ozone change as an upper boundary, the results shown on Figure 9 indicate that the lower altitude/Mach conditions will accommodate larger fleet sizes. These studies have been used as one factor for DAC continuing the Mach 1.6 baseline studies.

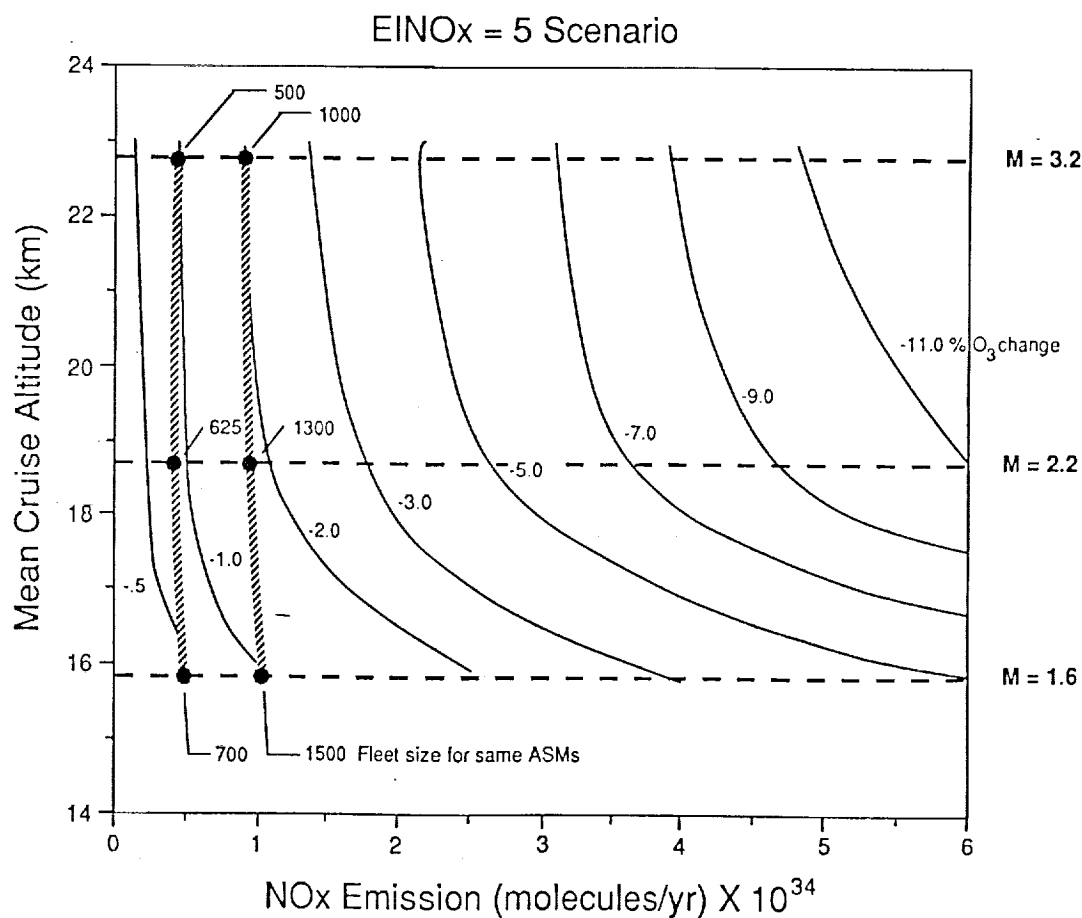


Figure 9

STAGE 3 NOISE STATUS AT MACH 2.2

Stage 3 noise limits may be met with advanced high augmentation suppressors as shown in Figure 10. Range has a very small effect on this conclusion but at 6,500 nmi and 883,000 lbs. the HSCT may not be economically viable.

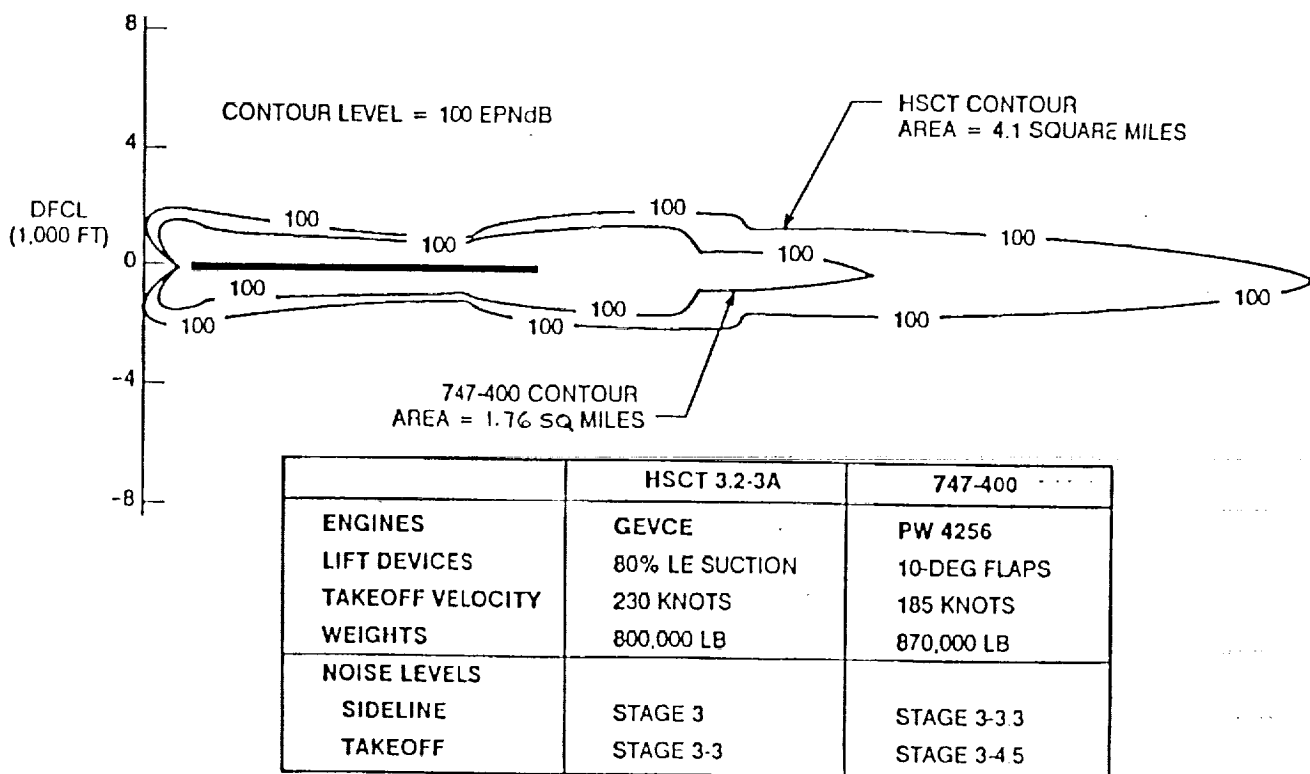
GE FLADE ENGINE (PS 50) CURRENT TECHNOLOGY HIGH LIFT PERFORMANCE

			SUPPRESSOR NOISE REDUCTION			
			11-12 EPNL		14-15 EPNL (ADVANCED)	
RANGE NMI	TOGW 1000lbs.	SLST 1000 lbs.	SIDELINE TAKEOFF (Δ EPNdB re STAGE3)		SIDELINE TAKEOFF (Δ EPNdB re STAGE3)	
5000	650	49.2	+3.1	+1.2	-0.2	-1.9
6500	883	66.6	+2.9	+1.5	-0.3	-1.6

Figure 10

THE HSCT NOISE CONTOUR IS LARGER THAN
THE 747 IF THE HSCT EXACTLY MEETS THE STAGE 3 SIDELINE
CERTIFICATION LIMIT

The community noise contours for both vehicles are shown in Figure 11. A 1990 Mach 3.2 cruise vehicle with goal level low speed performance has been used for the HSCT. The HSCT will have an increased impact on the community unless the technology can be developed to reduce the effect.



LRC012-20

Figure 11

CLIMB NOISE HSCT VS SUBSONICS

During the climb to cruise portion of the HSCT mission, the unsuppressed jet noise at ground level will be higher than either current stage 2 or 3 subsonic's as indicated in Figure 12. This higher noise level is a concern and will need suppressing and further study to establish the accuracy of these calculations and acceptable noise levels. Additional details are discussed in Session 8.

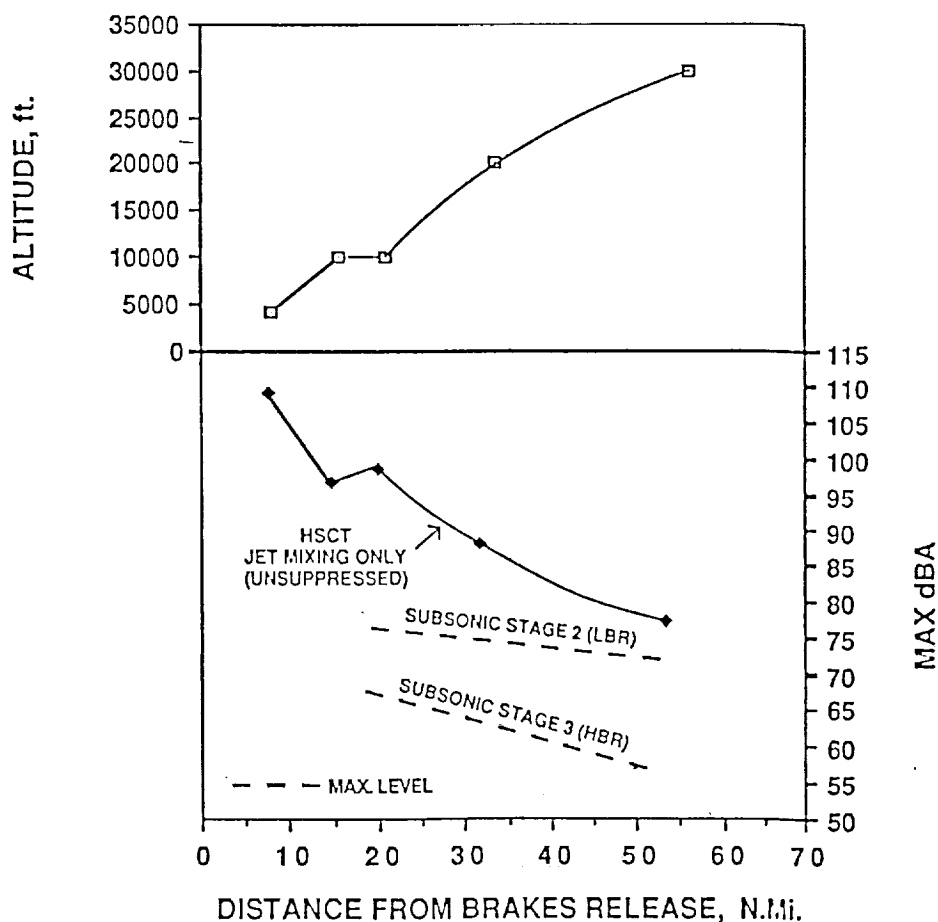
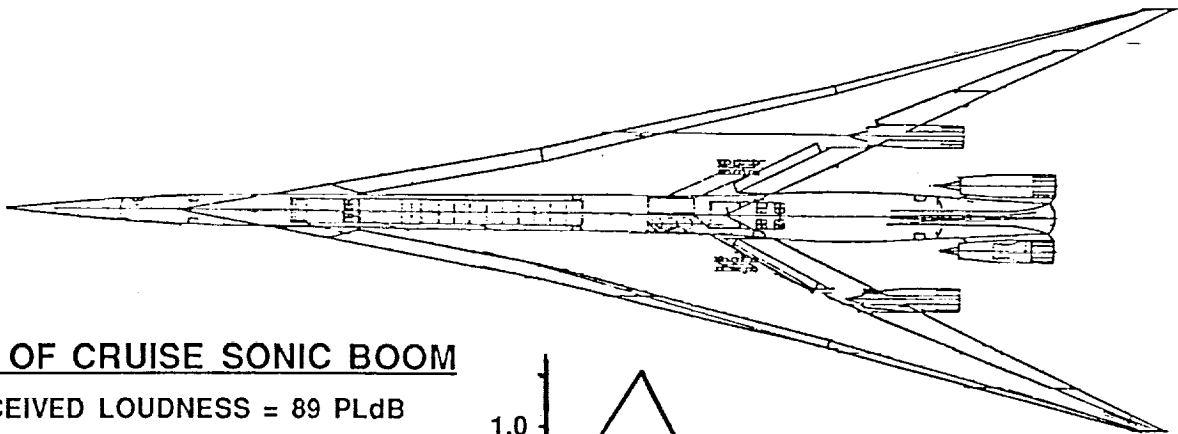


Figure 12

SONIC BOOM STATUS - SEPTEMBER 1990

The configuration shown on Figure 13 meets our sonic boom signature goal of 90 PLdB. However, the concept shown has an unacceptably high empty weight which results in a range short of our goal. Additional details are discussed in Session 5.

MACH 3.2 OVERWATER/ MACH 1.6 OVERLAND
286 PASSENGERS
355 FT. LENGTH



BEG. OF CRUISE SONIC BOOM

- PERCEIVED LOUDNESS = 89 PLdB
- SHOCK STRENGTH = 0.6 psf.
- MAX. OVERPRESSURE = 1.5 psf.

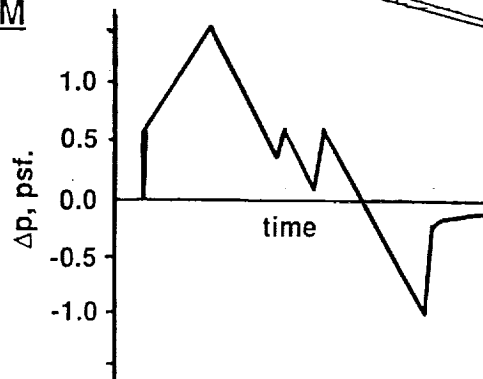


Figure 13

REQUIREMENTS TO ACHIEVE ENVIRONMENTAL GOALS

Suggested technology and study topics in the 3 environmental areas discussed is shown in Figure 14.

REQUIREMENT	GOAL
1) ATMOSPHERIC EMISSIONS	
<ul style="list-style-type: none">• COMBUSTOR EINO_x = 5• ATMOSPHERIC MODELS	NO GREATER THAN 1% OZONE DEPLETION FOR ECONOMIC FLEET SIZE
2) JET NOISE	
<ul style="list-style-type: none">• HIGH AUGMENTATION EJECTORS (60 TO 120%) OR HIGH INLET FLOW ENGINE CYCLE• NOZZLE SUPPRESSOR OR MIXER• LOW SPEED AERODYNAMICS	STAGE 3 LIMITS
<ul style="list-style-type: none">• ENGINE CYCLE• NOZZLE SUPPRESSOR OR MIXER• NOISE ESTIMATE VALIDATION	CLIMB TO CRUISE NOISE COMMUNITY NOISE ACCEPTABILITY
3) SONIC BOOM	
<ul style="list-style-type: none">• CONFIGURATION DEVELOPMENT & WEIGHT REDUCTION• WIND TUNNEL VALIDATION• HUMAN RESPONSE STUDIES	90 PLdB SIGNATURE AT ECONOMIC RANGE

Figure 14

MATERIALS AND STRUCTURAL CONCEPTS

The material systems and structural concepts being considered for the 1991 Mach 2.4 material design study are described in Figure 15. Additional details are discussed in Session 11.

MATERIAL SYSTEMS

CONVENTIONAL ALUMINUM ALLOYS

ELEVATED TEMPERATURE ALUMINUM

MONOLITHIC

DISCONTINUOUSLY REINFORCED

CONTINUOUSLY REINFORCED

TITANIUM PRODUCTS

POLYMERIC CARBON FIBERS WITH RESINS:

EPOXY

THERMOPLASTIC

BMI

PMR

STRUCTURAL CONCEPTS



HAT



BLADE



ZEE



HONEYCOMB

Figure 15

MDC 1991 MACH 2.4 MATERIAL STUDY DESIGN
FEATURES MULTIPLE MATERIALS

The current status of the materials concepts on various components of the aircraft are shown on Figure 16. The configuration features an all composite fuselage and a mixture of titanium and composites for the wing.

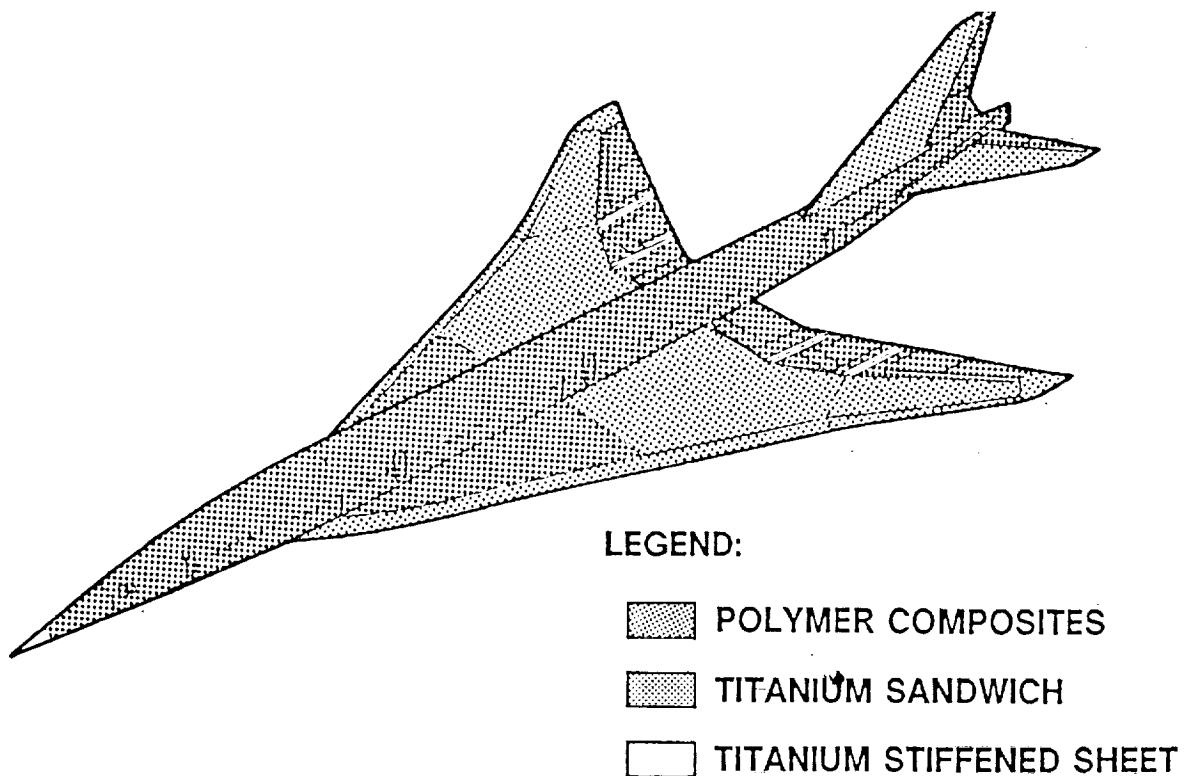


Figure 16

PROPULSION ASSESSMENT

The status of the propulsion system analysis is described in Figure 17.

- 4 ENGINE CYCLES & VARIANTS EVALUATED
 - FLADE } GE
 - VCE }
 - VSCE } P&W
 - TBE }
- P&W TBE AND GE FLADE ARE PREFERRED CONCEPTS
- NOISE SUPPRESSORS ARE REQUIRED TO MEET NOISE & PERFORMANCE CONSTRAINTS - ENGINE DERATE NOT ACCEPTABLE
- KEY TECHNOLOGIES/STUDIES
 - PERFORMANCE AT SUBSONIC AND SUPERSONIC CRUISE
 - HIGH AIRFLOW NOISE SUPPRESSORS
 - INTEGRATED CONTROL
 - AIRFRAME INTEGRATION
 - HIGH TEMPERATURE/LONG DURATION CRUISE

Figure 17

EVALUATION OF ENGINE CYCLES RESULTS
IN THE P&W TBE AND GE FLADE AS
THE PREFERRED CONCEPTS

Noise and performance assessments were made for the 4 basic engine cycles listed on Figure 18. The results were obtained during DAC's contract work in 1990 using a Mach 3.2 cruise vehicle. Based on the results shown on the Figure, the P&W TBE and GE Flade were selected for further study.

	TBE	VSCE	VCE	FLADE
NOISE	MEETS STAGE 3 WITH 120% PUMPING	MAY NOT MEET STAGE 3	3-5 DB OVER STAGE 3	MEETS STAGE 3 BASED ON GE DATA
PERFORMANCE TOGW (NO STAGE 3 LIMIT) TOGW (STAGE 3)	BASE 4.8% WORSE	11.2% WORSE	2.5% BETTER	0.4% WORSE 3.1% BETTER

Figure 18

1991 HSCT ENGINE SYSTEMS STUDIES PLAN

The task and schedule that the joint P&W/GE team have agreed on for engine cycle development is shown on Figure 19. DAC will be supplying the necessary inputs to the engine companies for cycle development throughout the year. The engine cycles will be available for airframe fly-off analysis starting in October of 1991.

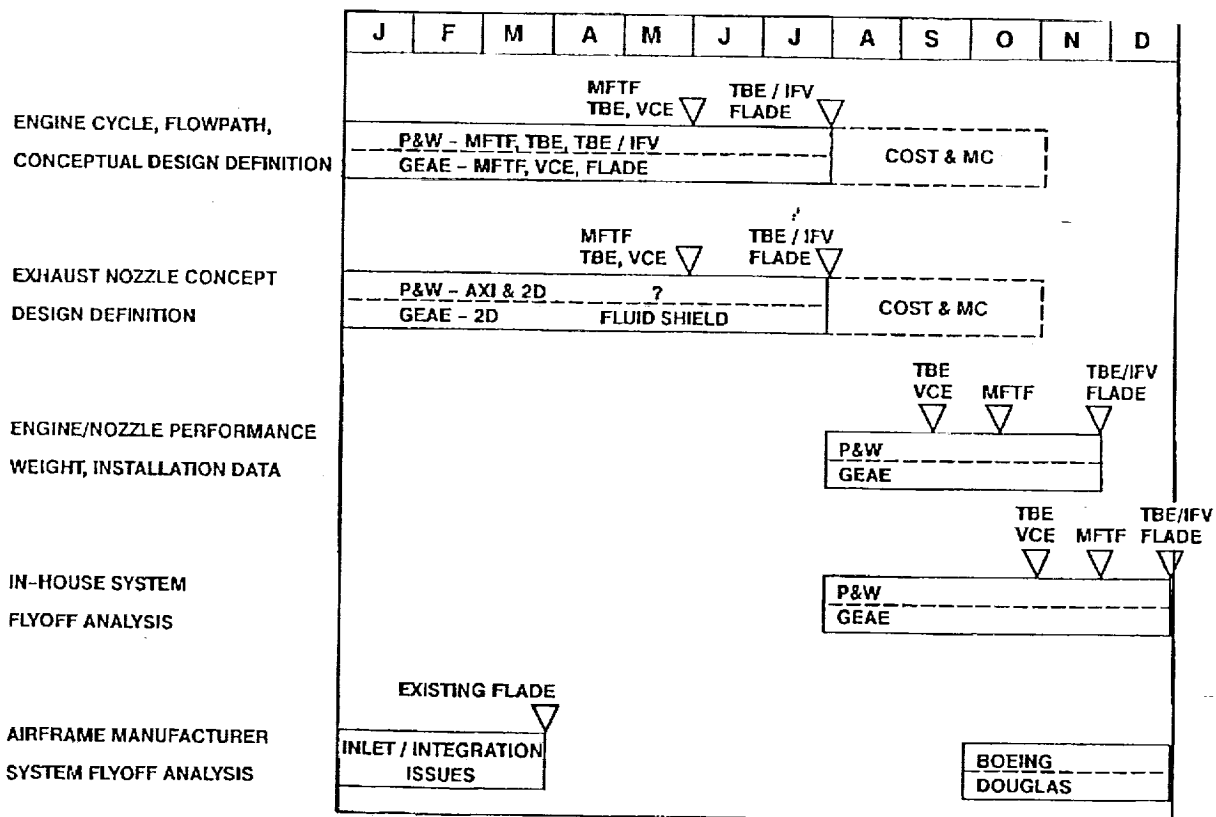


Figure 19

HIGH LIFT STATUS

The status of the high lift work is described in Figure 20. Additional details are discussed in Session 12.

- **AERODYNAMIC IMPACT ON PERFORMANCE AND NOISE HAS BEEN ESTABLISHED**
 - **RECOMMEND HIGH LIFT SYSTEM SETTING CHANGE DURING TAKE-OFF & CLIMB**
 - **NO IMPACT ON SIDELINE NOISE**
- **NEW PASSIVE DEVICES TESTED AT NASA DECEMBER 1990**
- **"PNEUMATIC" CONCEPTS TO BE TESTED AT NASA MID 1991**
- **IN HOUSE ANALYTICAL STUDIES INDICATE THAT THE DAC PERFORMANCE GOAL (S=80% TRIMMED) CAN BE ACHIEVED USING PASSIVE DEVICES**
- **KEY TECHNOLOGIES/STUDIES**
 - **VERIFICATION OF INNOVATIVE CONCEPTS**
 - **EXPERIMENTAL VERIFICATION AT HIGH REYNOLDS NUMBER**
 - **CFD APPLICATIONS**
 - **SUBSONIC CRUISE REQUIREMENTS**

Figure 20

BENEFITS OF HIGH LIFT PERFORMANCE IMPROVEMENT

Current technology community noise contours can be significantly improved if the high lift performance goal of 80 percent leading edge suction (LES) can be achieved as indicated by the results shown in Figure 21.

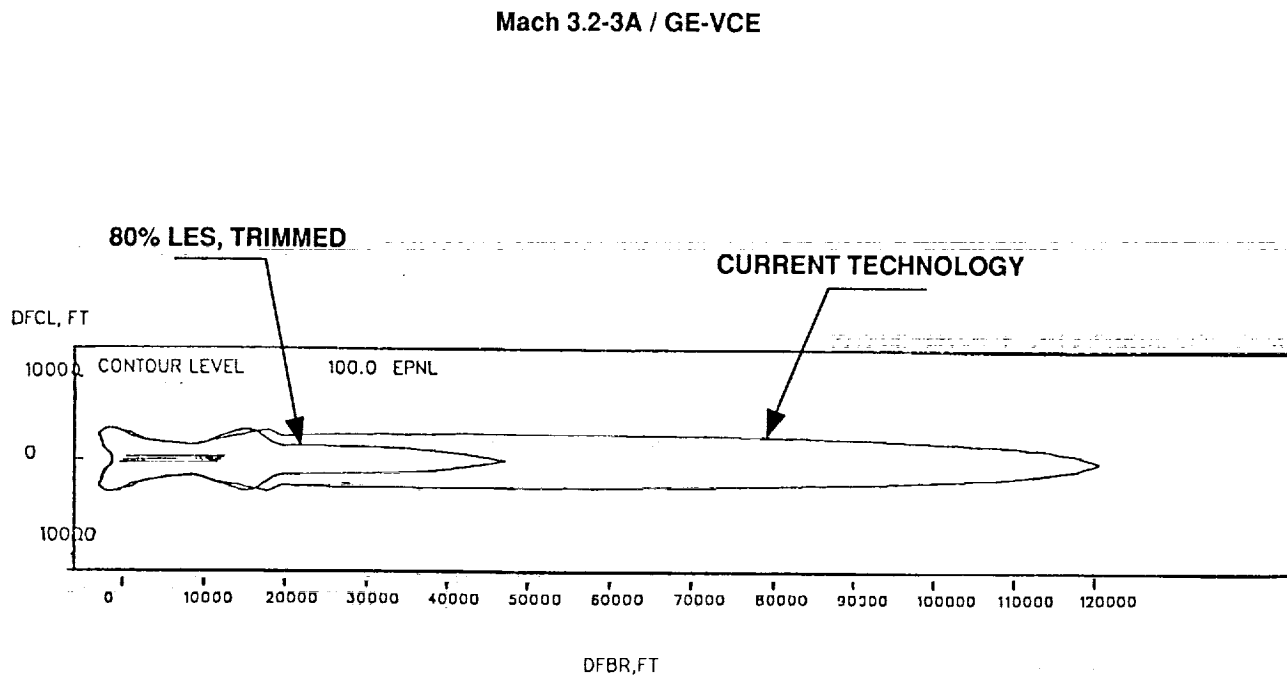


Figure 21

SUPERSONIC LAMINAR FLOW CONTROL (SLFC)

Previous studies at DAC under contract to NASA Langley have investigated the benefits of partial chord and full chord suction for laminar flow control. These studies indicated that full chord was the best system when evaluated on an economic basis. The benefits are shown on Figure 22 accompanied by the technology issues to be validated before these benefits can be achieved. Additional details are discussed in Session 13.

BENEFITS FOR HSCT	TECHNOLOGY ISSUES
● 8% TOGW REDUCTION	● CFD FOR HIGH SPEED ANALYSIS AND DESIGN
● 12% SMALLER ENGINES	● 3-D BOUNDARY LAYER STABILITY ANALYSIS PACKAGE
● 14% BLOCK FUEL REDUCTION	● PERFORATED ADVANCED MATERIALS DEVELOPMENT
● 11% L/D IMPROVEMENT	● DEVELOPMENT OF SLFC STRUCTURES AND DUCTING USING ADVANCED MATERIALS
● 4% BETTER ECONOMICS	● DEVELOPMENT AND INTEGRATION OF LARGE SUCTION MOTORS

Figure 22

FUTURE PLANS

DOUGLAS SYSTEM STUDY TASK STATUS FOR 1991

Douglas aircraft has recently been awarded an \$8 million 5 year task order contract to continue system studies to evaluate environmental compatibility and economic viability. DAC currently is under contract on 8 task orders as shown on Figure 23. Others are under negotiation and 3 are listed. DAC will also be continuing their own in house studies during the same period of time (see Figure 1).

TASK NO.	TITLE	STATUS	
		UNDER CONTRACT	NEGOTIATING
1.	PROGRAM MANAGEMENT	X	
2.	LOW SONIC BOOM PERFORMANCE/ECONOMICS	X	
3.	AESA SUPPORT	X	
4.	ATMOSPHERIC EMISSION EFFECTS	X	
5.	FLIGHT RESEARCH NEEDS	X	
6.	ECONOMIC METHODOLOGY	X	
7.	NOISE ASSESSMENTS	X	
8.	PROPULSION ASSESSMENTS	X	
9.	NOISE PREDICTION CODE VALIDATION (ANOPP)		X
10.	LFC ECONOMIC ASSESSMENT AT MACH 1.6		X
11.	SONIC BOOM MINIMIZATION		X

Figure 23

Session II. Airframe Systems Studies

CONT

High-Speed Research Program Systems Analysis Activities at Ames Research Center
George H. Kidwell, NASA Ames Research Center

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NASA Ames Research Center

**High-Speed Research Program
Systems Analysis Activities
at
Ames Research Center**

**George H. Kidwell
Chief, Systems Analysis Branch**

**High-Speed Research Workshop
May 15, 1991**

*58-05
12023*

N94- 33455

Systems Analysis Branch

The Systems Analysis Branch has been working to support the High-Speed Research Program for nearly one year now. This talk will present both the status of methodology development activities and the results of studies either completed or underway.

The initial discussion will involve the conceptual design synthesis program used for HSCT studies, ACSYNT, and enhancements that have been made specifically for HSRP.

The remainder of the talk will present some results for one study that has been completed and two that are underway. These are the advanced controls integration study, the fuel cost impact study, and the oblique wing configuration evaluation that is part of a larger innovative concepts investigation.

The talk will conclude with summary comments and observations.

Outline

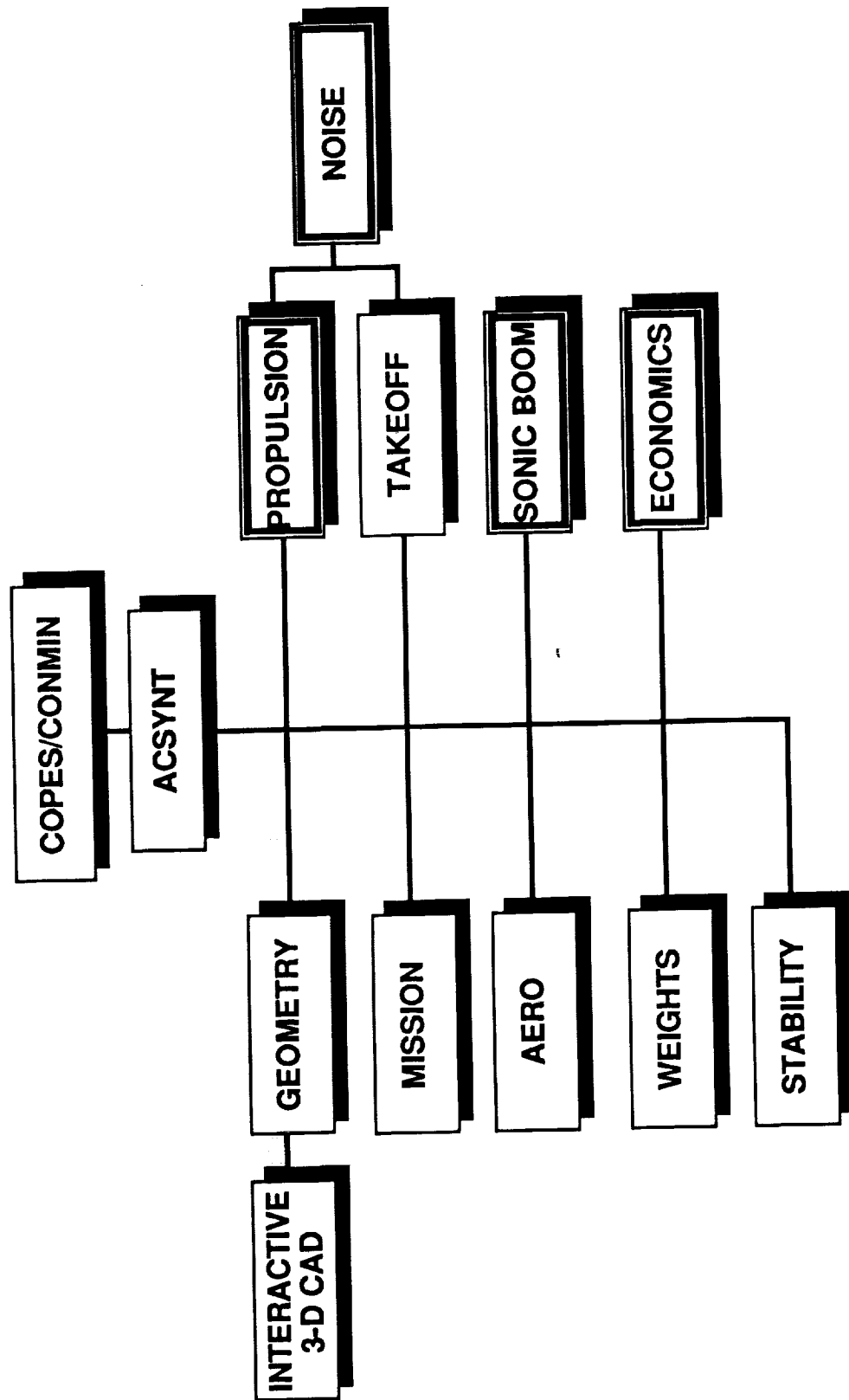
- **Design Synthesis Tool and Recent Enhancements**
- **Advanced Controls Integration Study Results**
- **Early Fuel Cost Impact Study Results**
- **Early Oblique Wing Configuration Study Results**
- **Summary**

ACSYNT (AirCraft SYNThesis) is NASA Ames' high performance aircraft conceptual/preliminary design synthesis computer program. It was originally developed at Ames in the early 1970's and has been in continuous use and modification ever since. It is characterized by a parametric description of a configuration, automatic design closure, and an integral optimization code. A key enhancement has been the Virginia Tech-developed geometric modeler that uses parametric variables to construct a NURBS (NonUniform Rational B-Spline) three-dimensional model for higher-order analysis and graphics. This module is shown as the interactive 3-D CAD element. While other methods are used for HSR studies within the branch, ACSYNT is the dominant tool.

The ASYNT Institute has been created as a joint enterprise between NASA, industry, and academia to actively develop and support the code among member organizations. Member organizations include many those currently involved in the HSRP, such as Boeing Commercial Airplanes, McDonnell-Douglas, General Electric Aircraft Engines, NASA Langley and NASA Lewis.

The new or substantially-enhanced modules necessary for HSR studies are highlighted in the figure.

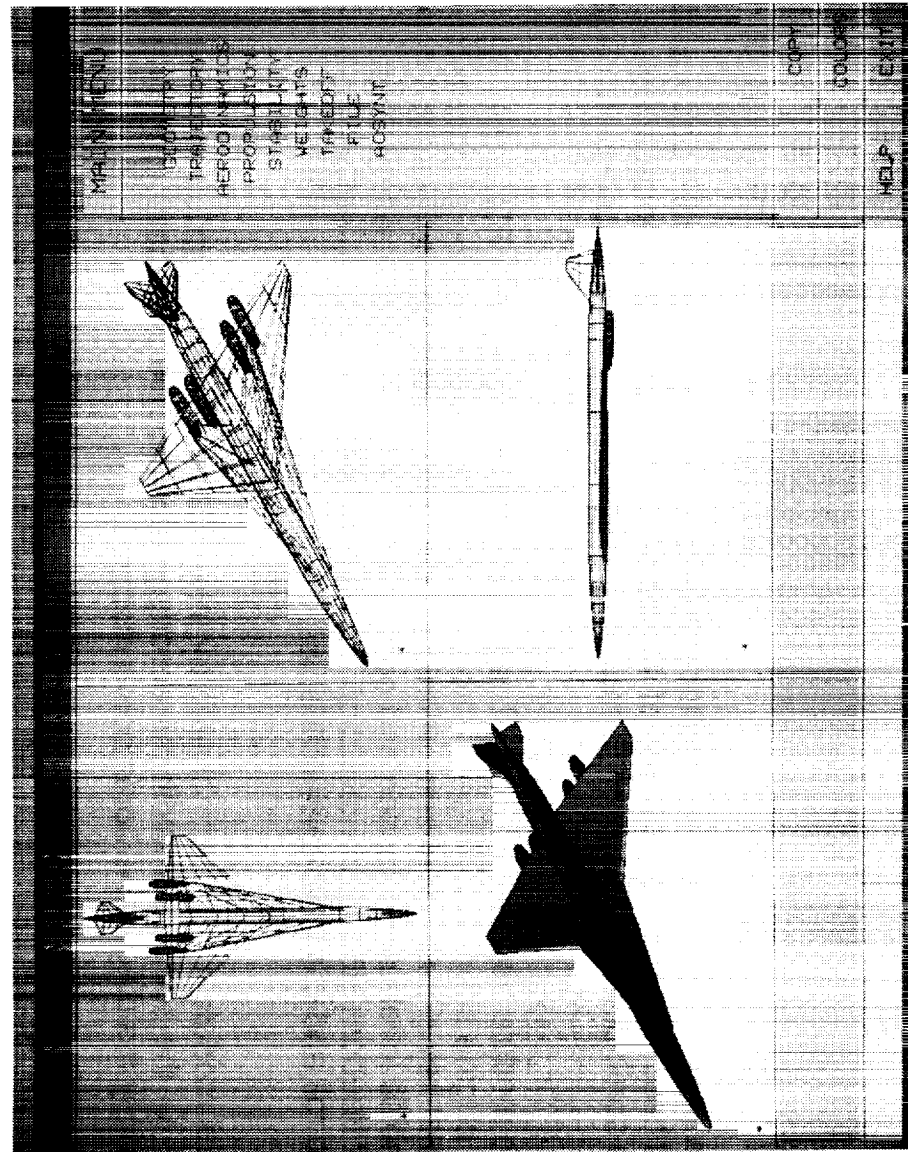
ACSYNT Structure



This figure shows the ACSYNT workstation display. It displays both wireframe as well as solid representations of the subject design.

The configuration has been defined solely using ACSYNT's parametric variables without any CAD manipulation of the geometry. A future development will allow the user to interactively modify the geometry and have it put back into parametric form for subsequent ACSYNT analysis and resizing.

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There have been several major enhancements to ACSYNT in response to HSR goals and constraints. These are the incorporation of sonic boom, economic, and noise analysis modules. The sonic boom and economic modules will be discussed in subsequent charts.

The takeoff noise module used with ACSYNT is the NASA Lewis program FOOTPR. It makes use of engine source noise generation with local noise attenuation to determine EPNdB levels at key ground locations. Within ACSYNT, it is used to evaluate FAA flyover and sideline noise levels during sizing and optimization. ACSYNT's takeoff module, a two-degree of freedom time-step integration digital simulation, is used to determine the takeoff ground roll and climbout characteristics.

The aerodynamics module has been improved by integrating the aerodynamic analysis methods used for the sonic boom with the aerodynamics module parametric methods, as opposed to strictly residing in the sonic boom module.

The propulsion module has been improved in two ways. First, methods have been developed to expand an engine database based on sparse data. Also, the cycle analysis option is being significantly improved to permit accurate estimates of propulsion system performance based on engine cycle data.

ACSYNT Enhancements for the HSR Program

- **Sonic Boom Module Development and Integration**
- **Economic Module Integration**
- **Takeoff Noise Module Integration**
- **Advanced Aerodynamic Methods Integration**
- **Propulsion Cycle Analysis Enhancement**

A sonic boom module was added to ACSYNT to permit the evaluation of sonic boom characteristics during the design synthesis process. The analytical method was constrained by the need for rapid execution and compatibility with the ACSYNT geometric model

The analysis makes use of three existing computer programs. The Harris wave drag routine is used to compute the equivalent body of revolution due to volume. A supersonic wing analysis (Carlson and Miller) computes the chordwise lift distribution, and hence the equivalent area due to lift. With the complete equivalent body of revolution known, the sonic boom propagation code of Hayes, Haefel, and Kulrud is used to extrapolate the signal and locate any shocks. This integrated analysis code allows the user to easily input an arbitrary aircraft configuration and calculate lift, drag, moment, and sonic boom characteristics. The user input is either a simple parametric description or a CAD-generated description of the aircraft. The geometric modeller makes it possible to use this analysis with a parametric definition of the vehicle.

The results from this module can be used in several ways. During configuration optimization, the sonic boom overpressure can be used as a constraint to make certain some maximum value is not exceeded. Also, the sonic boom characteristics can be used as the objective of the optimization in an effort to minimize one of the key parameters (overpressure, etc.). Of course, these results can merely be passed to the user for information and not used in the course of an optimization.



Ames Research Center

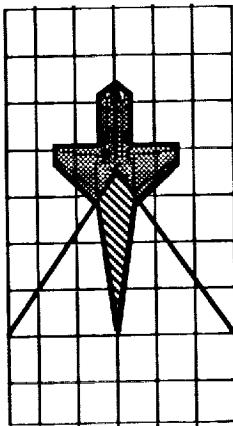
ACSYNT Sonic Boom Module

ACSYNT
Parametric Definition

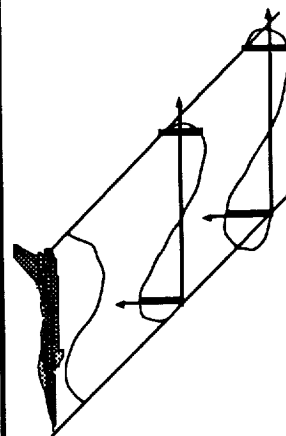
Harris Wave Drag Analysis



Supersonic Wing Analysis



Sonic Boom Propagation Code



Systems Analysis Branch

The transport cost module for ACSYNT consists of four major components as shown on the facing chart. Two components, Aircraft Manufacturing Costs and Manufacturer Return on Investment (ROI), assess economic parameters critical to production viability. The other two components, Airline Operating Cost and Airline ROI, determine the potential viability for a typical airline operation.

The Aircraft Manufacturing Costs consist of research, development, test and engineering (RDT & E), and production manufacturing and sustaining costs for a range of production quantities to determine unit cost to build.

Manufacturer ROI considers the cash inflows and outflows over a specified development and production period to assess the cost to build and pricing required to achieve a reasonable return on investment.

Airline Operating Costs consist of the direct costs associated with operating the aircraft and indirect costs related to servicing the aircraft and passengers for various stage lengths.

Airline ROI analyzes the operator's cash flow over a specified operating period and assess the revenue requirements in relationship to aircraft price to achieve an acceptable return on investment.

ACSYNT Transport Cost Module Flow



UNIT	ACQUISITION	RDT & E
------	-------------	---------

**MANUFACTURER
CASH-FLOW
ROI**

MANUFACTURER ROI VS PRICE

[illegible]

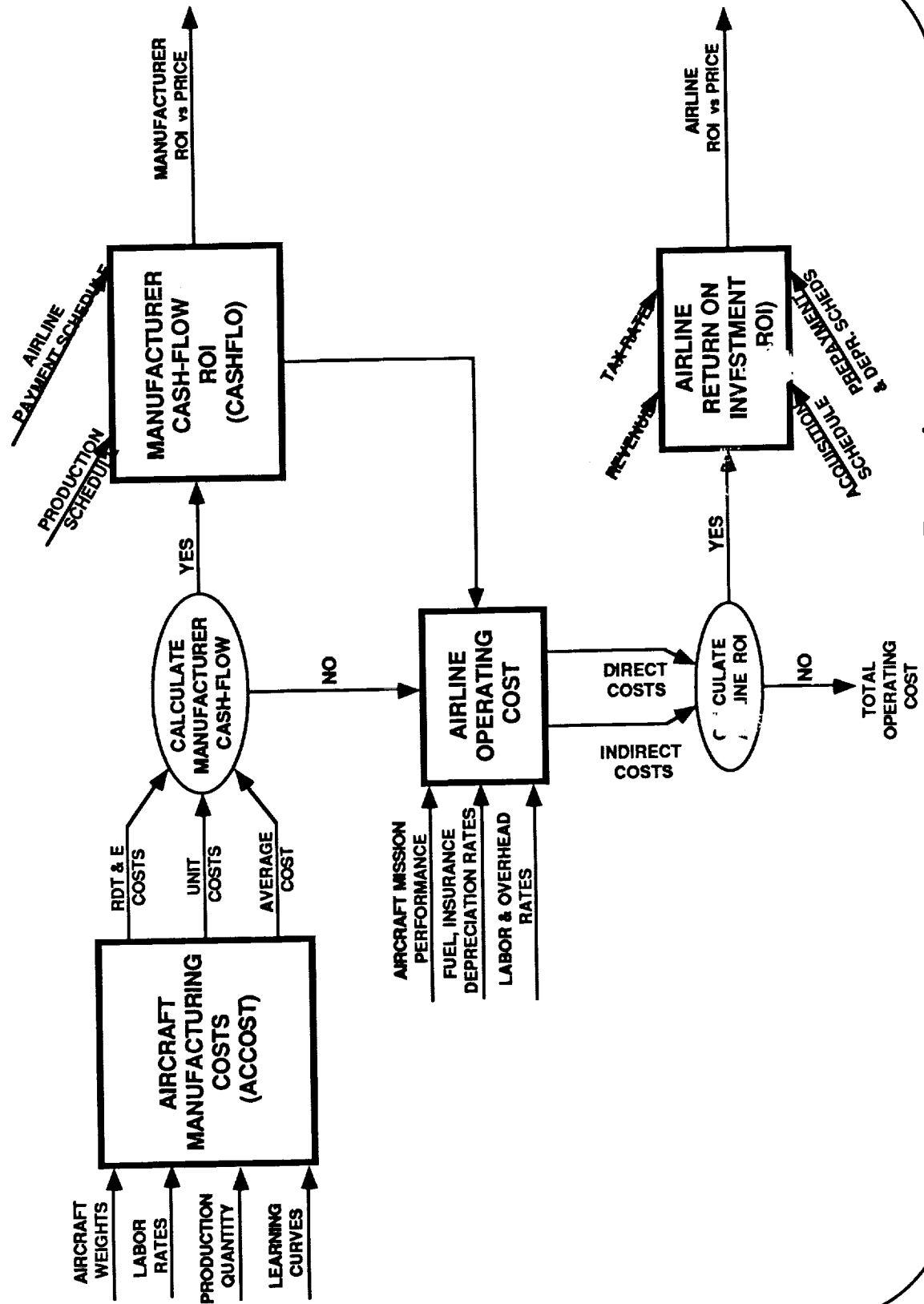
AIRLINE RETURN ON INVESTMENT

The facing chart depicts the flow of data and input parameters for the ACSYNT transport cost module. There are two basic paths that are of interest. One is to estimate the manufacturers unit cost and typical airline operating costs. The second, more detailed, path is to assess the potential rate of return on investment (ROI) to both the manufacturer and airline operator over a specified period of time as affected by aircraft price, airline revenue, and aircraft production quantity.

ACSYNT weight, propulsion, and performance modules are utilized to determine the aircraft component weights, engine size, and mission performance parameters, such as block time and fuel, that are passed to the modules that determine aircraft manufacturing and airline operating costs. Additional parameters, such as labor rates, learning curves, production quantity, fuel costs, and operational factors are input separately.

If ROI calculations are desired, additional production, payment, and depreciation schedules over a specified time period are required. Manufacturer ROI is determined as a function of aircraft price for various production quantities and Airline ROI is determined as a function of price for various revenue levels. The required production quantity and revenue level can then be determined to achieve viable ROI's for both the manufacturer and operator.

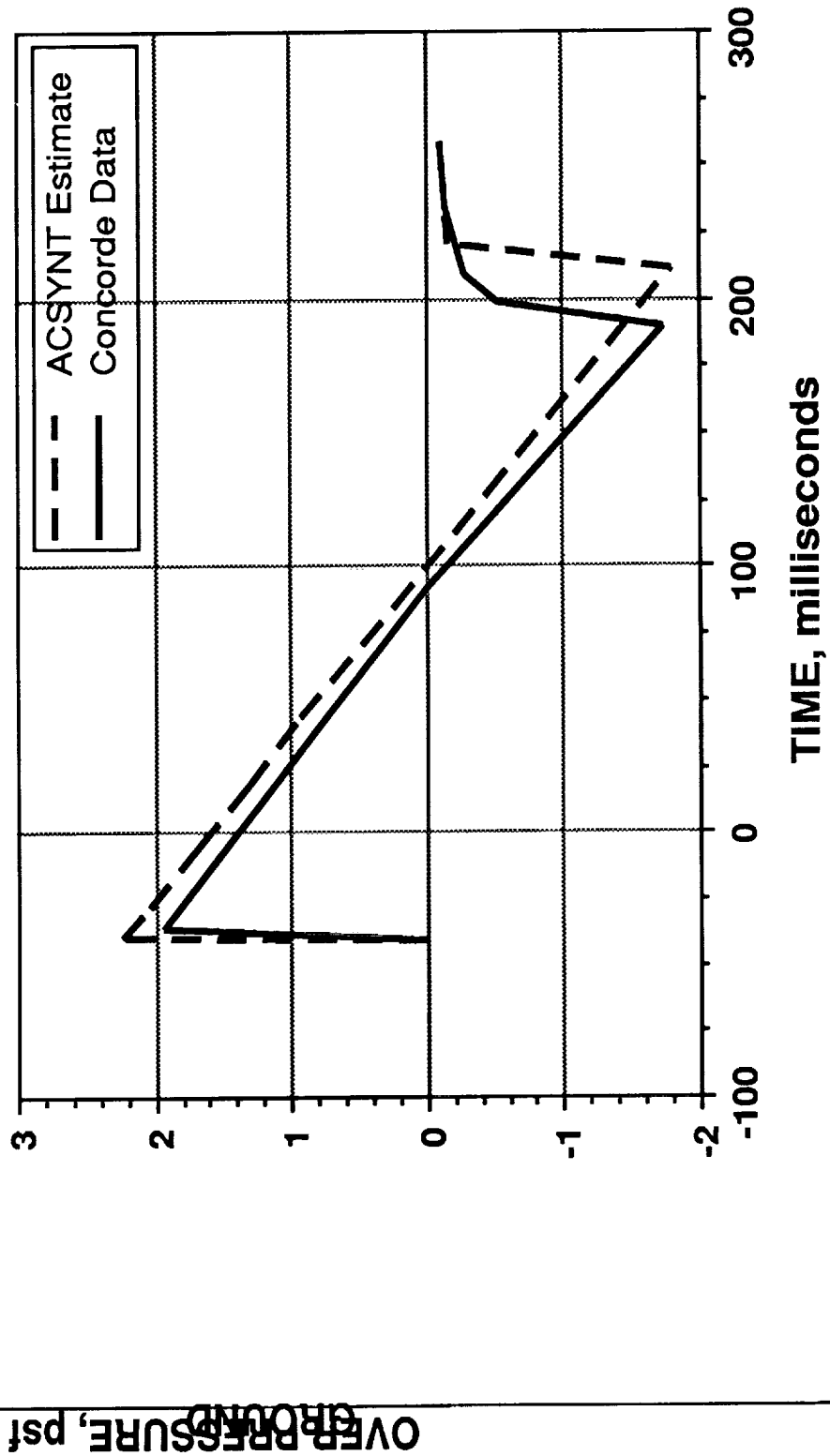
ACSYNT Transport Cost Module Details



This figure shows the result of a correlation between measured sonic boom overpressure at the ground for the Concorde and predicted levels using ACSYNT. In general, the agreement is good except for a small overprediction in magnitude and a stretching of the time scale. The error is possibly due to inaccuracy in the geometric model of the Concorde due to a lack of detailed configuration data and efforts are underway to complete the validation.



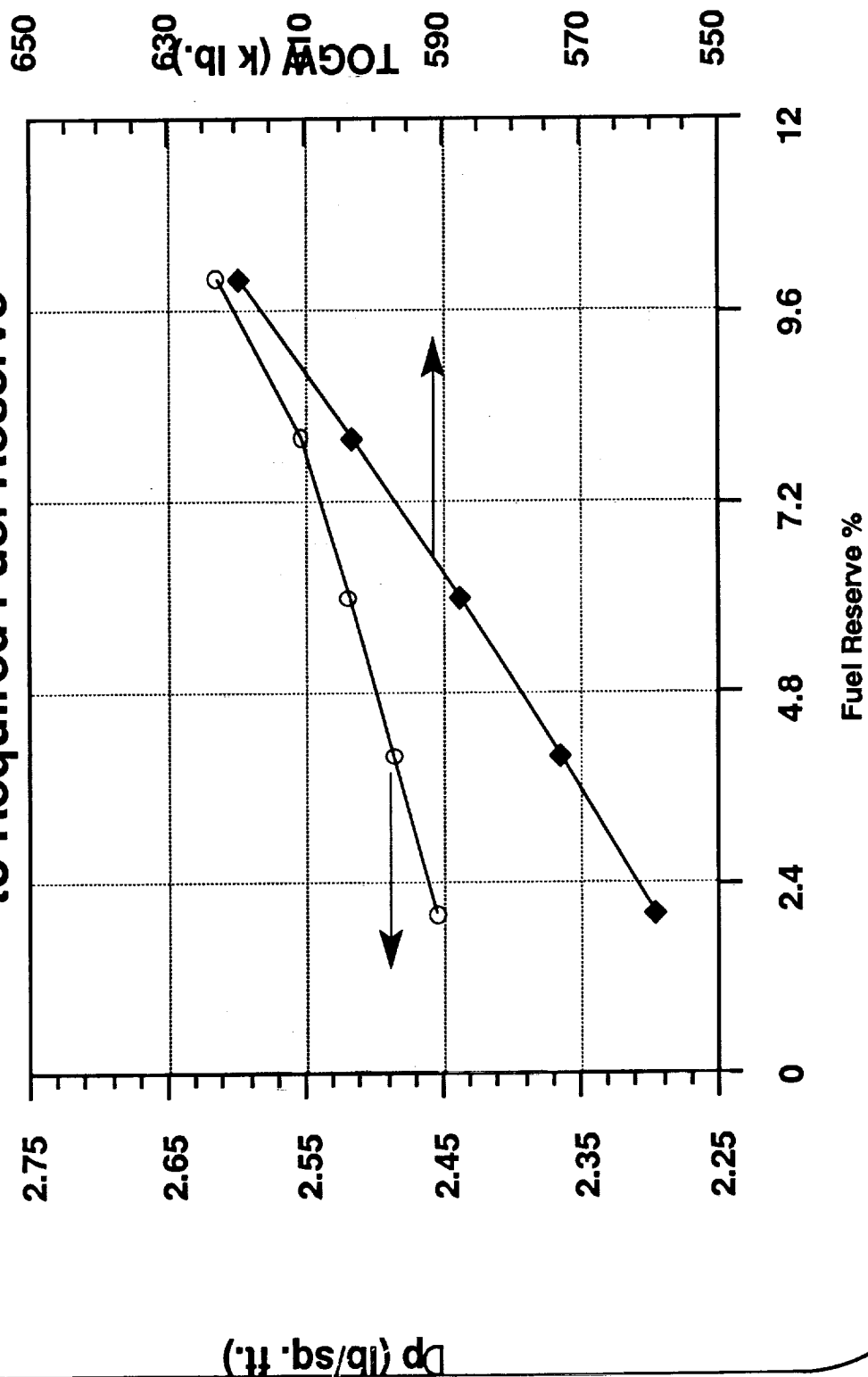
Sonic Boom Estimate Results



This figure shows a typical use of the sonic boom analysis in parametric sensitivity studies. Specifically, it shows how takeoff gross weight and sonic boom overpressure vary with fuel reserve requirements. Increasing reserve requirements increases the fuel weight and through the growth factor, the aircraft gross weight. The overpressure varies with vehicle size and weight.

The significance of this figure is the speed in which parametric tradeoffs can be performed. The five datapoints were achieved with a single run of ACSYNT lasting only several minutes on a Silicon Graphics Iris workstation.

Sensitivity of Boom and Gross Weight to Required Fuel Reserve



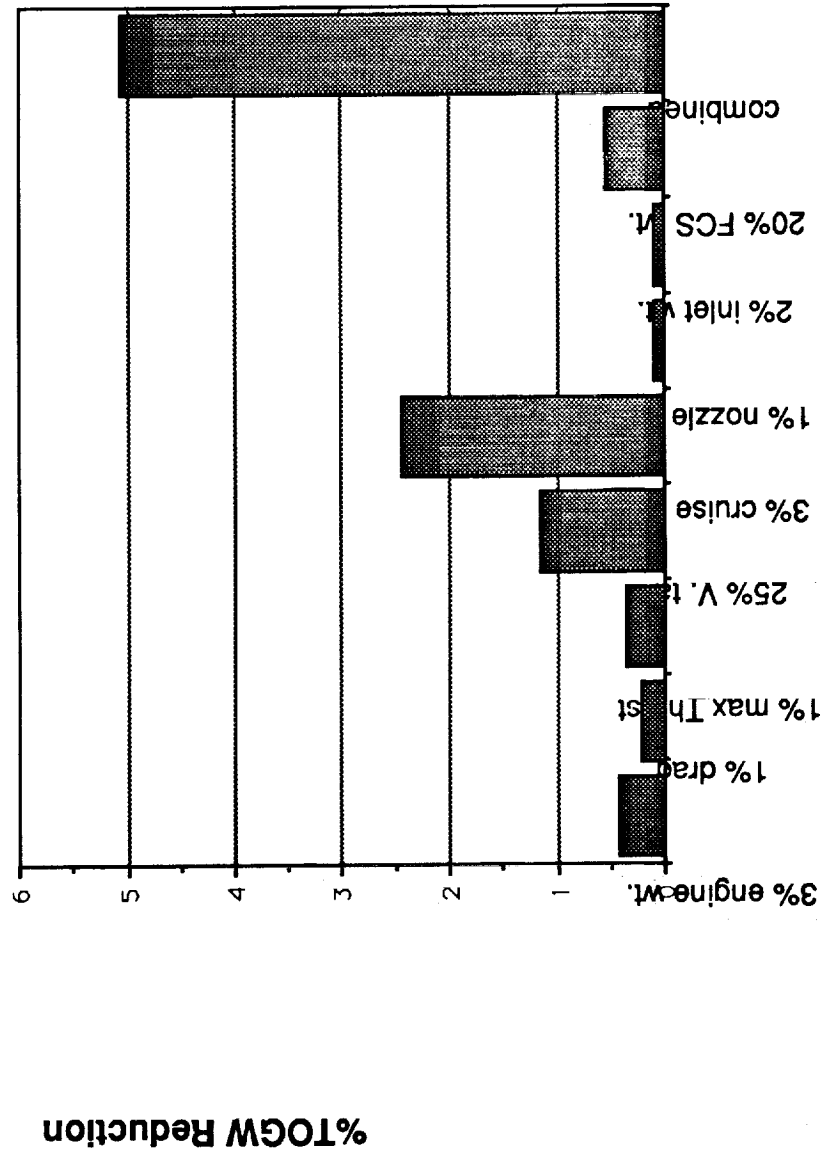
This figure presents a summary of the results of a study of integrated flight-propulsion control concepts for HST aircraft. In this study, advanced control concepts are identified and their impact on the propulsion and/or airframe estimated. The impact on the integrated vehicle of these effects, individually and together, was evaluated using ACSYNT. The baseline design used 1995 technology engines, carried 250 passengers, and had a range of 5,000 nm. at Mach 2.4 with normal reserves.

The results show the benefits of the following concepts:

- integrated engine/flight controls, producing reductions in engine and nozzle weight.
- integrated inlet/engine/flight controls, producing lower inlet drag (expressed as a percent decrease in aircraft drag), and higher inlet recovery and maximum thrust.
- performance seeking control, resulting in improvement in cruise SFC.
- automatic control of engines following engine loss at takeoff rotation, leading to reduced vertical tail size.
- emergency minimum thrust mode, enabling an inlet weight reduction.
- integrated control architecture, leading to a 20% flight control system weight reduction.

As shown, the combined impact on the vehicle is more than 5%. Details of this study are available in SAE conference paper 901928 or NASA TM 101728 by Burcham, Gilyard, and Gelhausen.

Sensitivity of HSCT Takeoff Weight to Airframe-Propulsion Integration



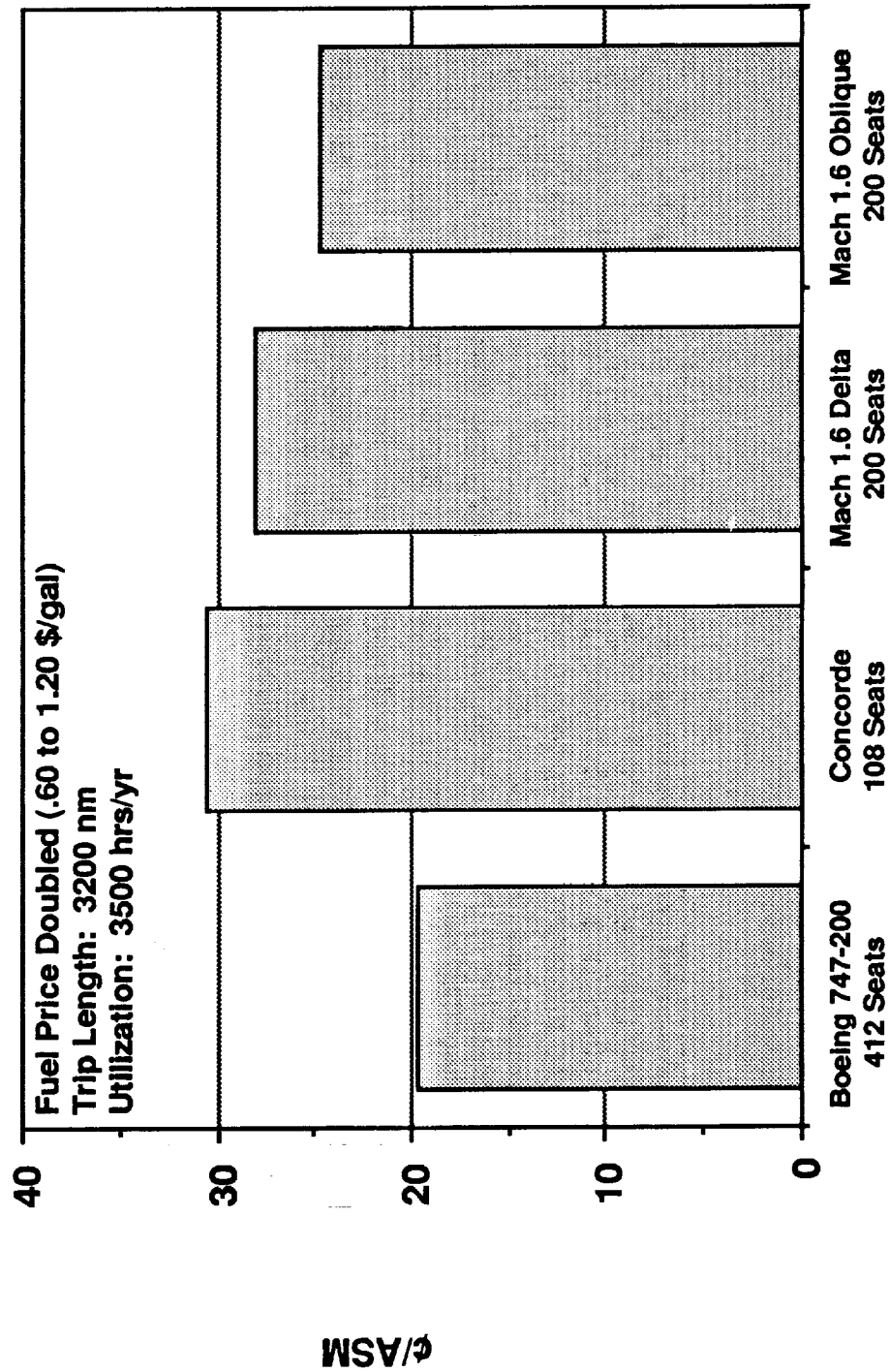
In light of increased fuel prices over the last six months, it is of interest to examine the sensitivity of HSCT aircraft direct operating cost (DOC) to fuel cost. Is the sensitivity so high as to jeopardize the economic feasibility of HSCT aircraft? How does the sensitivity compare to that of subsonic transports?

This study compares the percent increase in DOC due to doubling the price of fuel for the Boeing 747-200, the Concorde, a Mach 1.6 delta configuration, and a Mach 1.6 oblique wing/body. The ACSYNT cost methodology was used to estimate the aircraft manufacturing costs and airline operating costs in 1990 dollars for a production of 400 aircraft. A fuel price of \$0.60 and \$1.20 per gallon was used and the utilization of each aircraft was fixed at 3500 hours per year. The 747 has twice and the Concorde half the number of passengers carried by the Mach 1.6 aircraft. Basic characteristics of the aircraft are:

<u>Parameter</u>	<u>B747</u>	<u>Concorde</u>	<u>Delta</u>	<u>Oblique</u>
Gross Weight	776058	399100	603849	529380
Passengers	412	108	200	200
Design Mach	0.84	2.0	1.6	1.6
For 3200n.mi Stage				
Block Time	7.2 Hr	3.7 Hr.	4.5 Hr.	4.5 Hr.

The results show that the DOC for the 747 increases 20%, for the Concorde over 30%, approx. 28% for the delta and 25% for the oblique wing. These results are preliminary and represent the very beginning of this study.

Fuel Price Sensitivity



This is an ACSYNT-generated image of the Mach 1.6 oblique wing/body configuration that is being evaluated as part of an innovative concept study. It is based on a 1975 Boeing study for a transport cruising at Mach 1.2. The wing weight is based on that study and therefore is conservative with respect to today's technology level. The configuration has four engines mounted in the rear of the fuselage, two high and two low exhausting in the base area, with side-mounted inlets. The engines are the Pratt & Whitney TBE cycle.

This design was resized for Mach 1.6, as was the delta wing baseline that was derived from a 1988 HSCT design. Thus, the baseline aircraft technology levels were not the same and the results are conservative with respect to the oblique wing.

These results are preliminary and are subject to change. The wing/body analysis is a precursor to a follow-on oblique flying wing study.

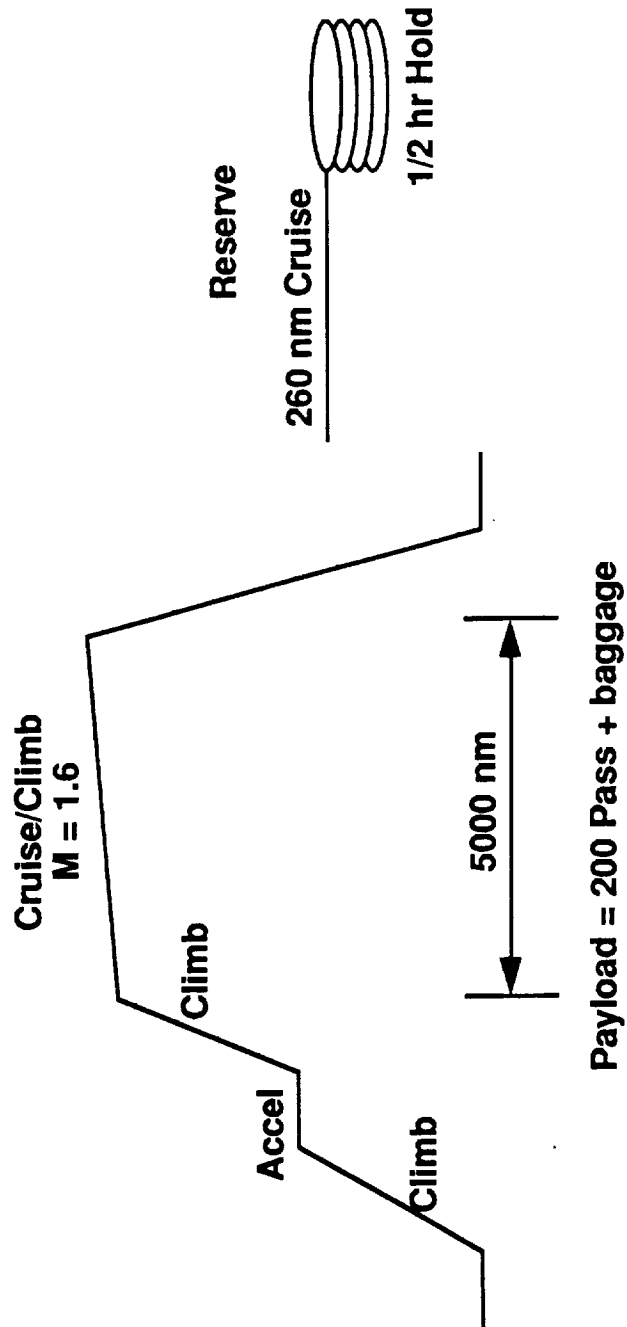


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This figure shows the design mission for this study.

Oblique Wing Initial Sizing Studies

Design Mission



This table shows a comparison of some key parameters for the oblique and delta configurations. The subsonic L/D for the oblique is higher for the oblique wing due to the higher aspect ratio and improved lift curve slope of the lower sweep oblique wing. The higher supersonic L/D of the oblique is due primarily to lower wave resulting from an improved cross-sectional area distribution..

The vastly improved takeoff and landing performance of the oblique comes from the improved low speed characteristics of an unswept wing.

Aircraft Comparison

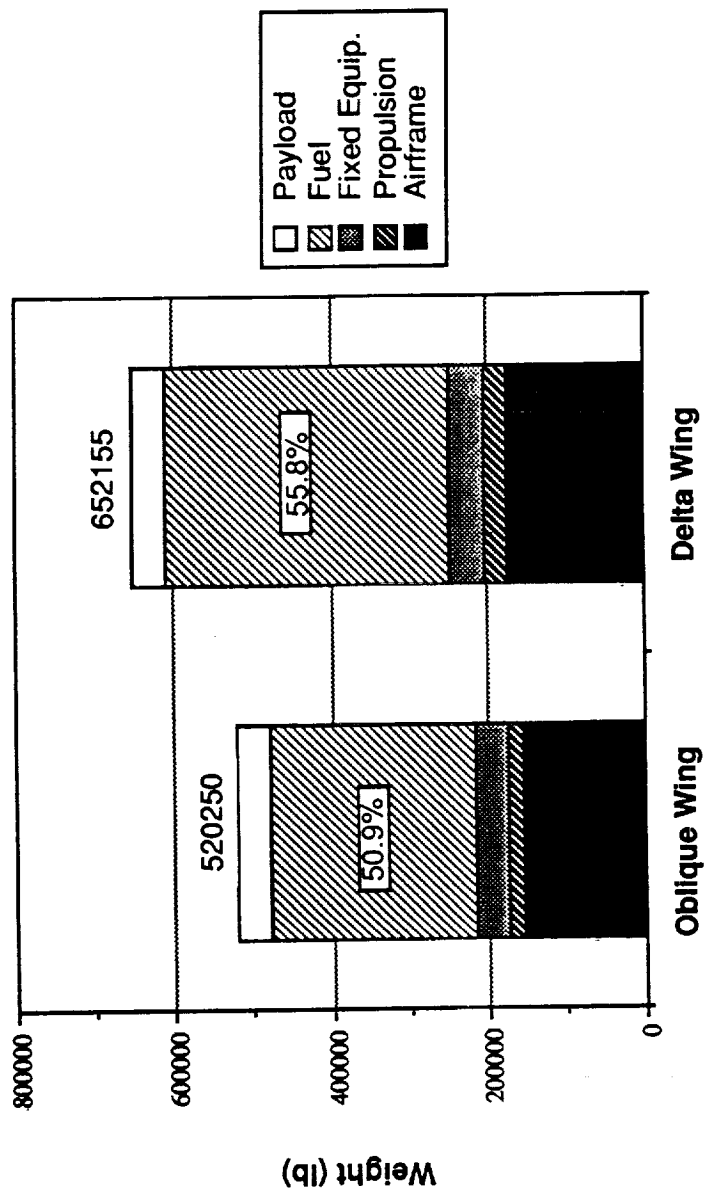


Oblique Wing Delta Wing

Gross Weight	520250 lb	652155 lb
Engine Thrust	31345 lb	49000 lb
Fuel Weight	265036 lb	364191 lb
Takeoff Length	6254 ft	8860 ft
Landing Length	5316 ft	10000 ft
Supersonic L/D	10.95	9.21
Subsonic Cruise L/D	16.0	13.0
Wing Area	4000 sq ft	5900 sq ft
Wing Span	174 ft.	128 ft.

This figure shows the weight breakdown for the two configurations. Two of the oblique wing's advantages are apparent here. First, the higher structural efficiency of the oblique wing results in much lower structural weights for the wing and fuselage. Secondly, the higher cruise L/D of the oblique wing results in improved fuel efficiency, and hence lower fuel requirements. These two effects, when integrated over the vehicle's design, results in a savings of approximately 20 percent.

Weight Breakdown



The Systems Analysis Branch at Ames Research Center has been involved in the HSR program for nearly a year. The majority of this activity has involved enhancements to the ACSYNT conceptual design synthesis program. These enhancements have centered on analyses of particular importance to HSR, including sonic boom, noise, and economics.

One limitation of these studies has been in the data available to represent current HSCT configurations. An effort will be made to correct this deficiency.

As shown, the fuel cost impact study and the oblique wing study are in the early stages and will be continued and completed in the coming months. Results will be released as appropriate.

Additional study activities of the branch will be assigned by the Systems Integration Steering Committee of the High-Speed Research Program. Ames will generally be responsible for economic studies, innovative concept studies, and parametric sensitivity studies.

Summary

- FIRST YEAR OF ACTIVITY HAS CENTERED ON CODE DEVELOPMENT AND LIMITED STUDIES
- ADDITIONAL DATA NEEDED FOR BASELINE CONFIGURATIONS
- FUEL COST IMPACT, OBLIQUE WING STUDIES TO BE CONTINUED AND COMPLETED
- OTHER STUDIES TO BE ASSIGNED BY SYSTEMS INTEGRATION STEERING COMMITTEE

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Session II. Airframe Systems Studies

Overview of Langley Systems Studies
Samuel D. Dollyhigh, NASA Langley Research Center

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OVERVIEW OF LANGLEY SYSTEMS STUDIES

SAM DOLLYHIGH

Presented at the First Annual High-Speed Research Workshop
Williamsburg, Virginia

May 15, 1991

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WHY NASA SYSTEMS STUDIES?

SELF-EXPLANATORY

WHY NASA SYSTEMS STUDIES?

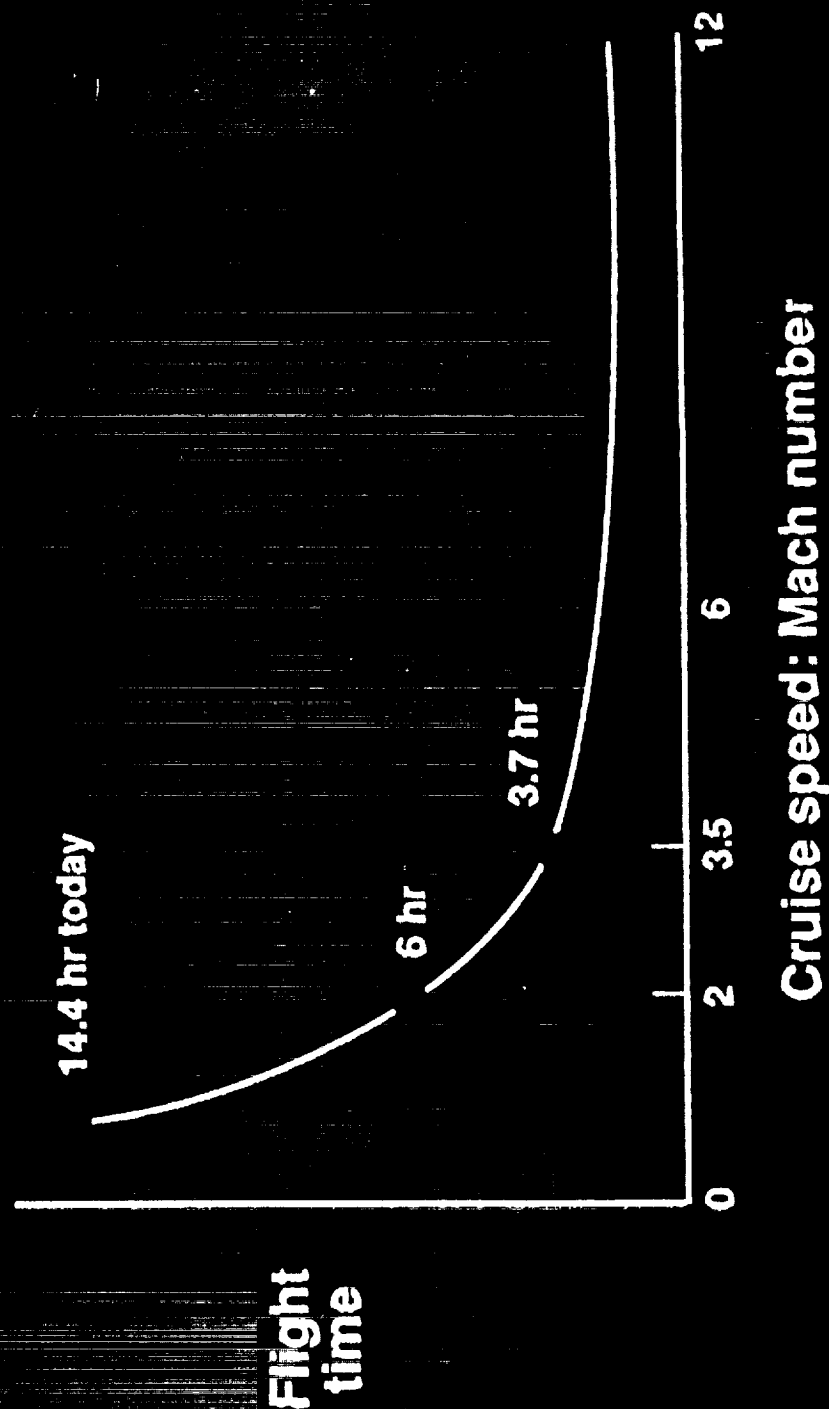
- **ONLY AIRCRAFT SYSTEMS STUDIES CAN QUANTIFY THE OVERALL EFFECTS OF TECHNOLOGY STUDIES AND INDICATE VIABLE SOLUTIONS**
- **SYSTEMS STUDIES ARE NECESSARY TO PROVIDE INPUTS TO ASSESS COMMUNITY NOISE AND SONIC BOOM LEVELS**
- **PROVIDE CONTINUING FOCUS FOR TECHNOLOGY STUDIES**
- **IN-HOUSE STUDIES MAKE NASA A BETTER "CUSTOMER" AND REMOVE COMPANY BIASES**
- **MAJOR BENEFITS OF VEHICLE INTEGRATION STUDIES IN A RESEARCH INSTITUTION**
 - Guide to Discipline Research
 - Technology Evaluation
 - Identification of High-Payoff Technologies
 - Foster Innovation
 - Identify Associated Research Required for Technology Application
 - Expedite Technology Transfer

CRUISE SPEED: MACH NUMBER

A good systems analyst will spend some time examining the question or problem before attempting to generate aircraft concepts in response to a set of requirements. This figure presents flight time versus cruise Mach number for an aircraft that experiences an average acceleration and deceleration of 0.2 g and has a range of 6500 n.mi. One does not need a series of aircraft concepts to generate such a curve, just a knowledge of physics. A simple aircraft mission performance program is useful to get the climb and descent times right. Based on this information, Langley decided to examine HSCT concepts in the Mach 2.0 to 4.0 range, which captures the knee of the curve. Mach 4.0 was chosen as the maximum for the in-house studies based on a desire to stay with turbojet propulsion systems. A tremendous jump in technical complexity occurs above Mach 4.0 and would most certainly be post year 2005 before commercial application. The nature of the curve of flight time versus Mach does not change rapidly with range and/or acceleration. Very large accelerations would be required to make the higher Mach numbers payoff. Note that for commercial application 6500 n.mi. range captures over 90 percent of the long range market so longer ranges hold relatively little commercial interest (it is simple geography and population location). Also, the average mission range in airline service is much less than the design mission, which further reduces the benefits of higher Mach numbers.

HIGH-SPEED CIVIL TRANSPORT

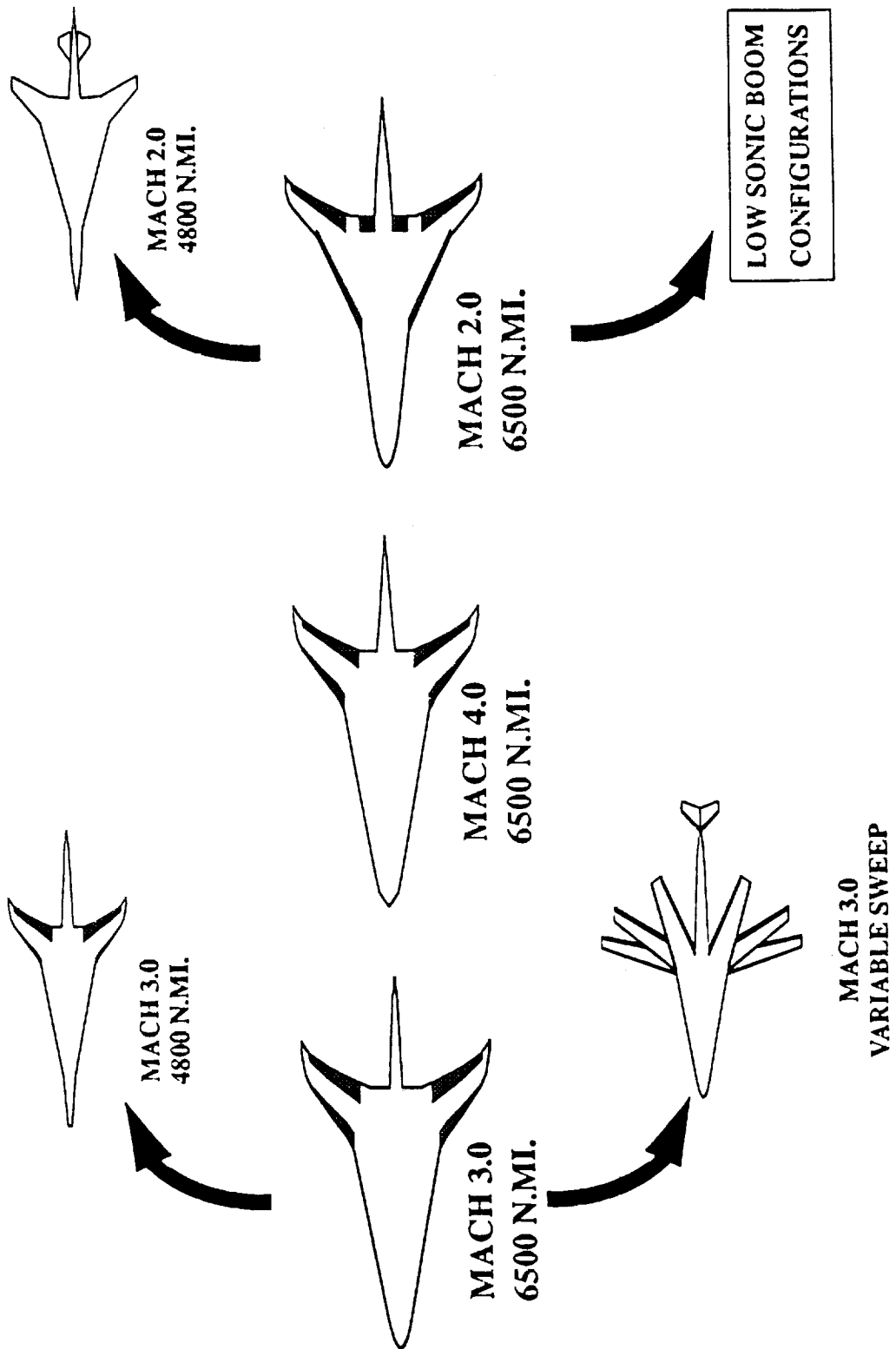
Flight Time and Cruise Speed
6500 n mi trip



CONFIGURATION STUDIES 1987-1990

The progression of early configuration studies is illustrated in this figure. The Langley studies were initiated at Mach 3.0 to examine the technologies required to achieve reasonable range/payload characteristics. Mach 3.0 was chosen principally to be within the range of thermally stabilized Jet A (economic viability) aspects and as representative of a modest technological challenge. Next, the upper end of the Mach range of interest was studied with a Mach 4.0 concept. Using year 2015 technology projections, this concept was found to be too heavy, even before environmental issues were addressed. The lower end of the Mach spectrum of interest was then examined with the Mach 2.0 concept. The resulting takeoff gross weights of these concepts will be presented in the next figure. The effects of reduced range were determined on the Mach 2.0 and 3.0 concepts, but not on the Mach 4.0 concept since high speed and reduced range tend to be incompatible. A variable sweep Mach 3.0 concept was also studied in an attempt to resolve the need of good low-speed characteristics for takeoff, landing, and subsonic overland flight with good supersonic cruise efficiency. The results of this study will be discussed in more detail on subsequent charts. Although some low sonic boom configuration work was done at Mach 3.0, the primary focus of the vehicle systems studies on low-boom concepts has been Mach 2.0 and below.

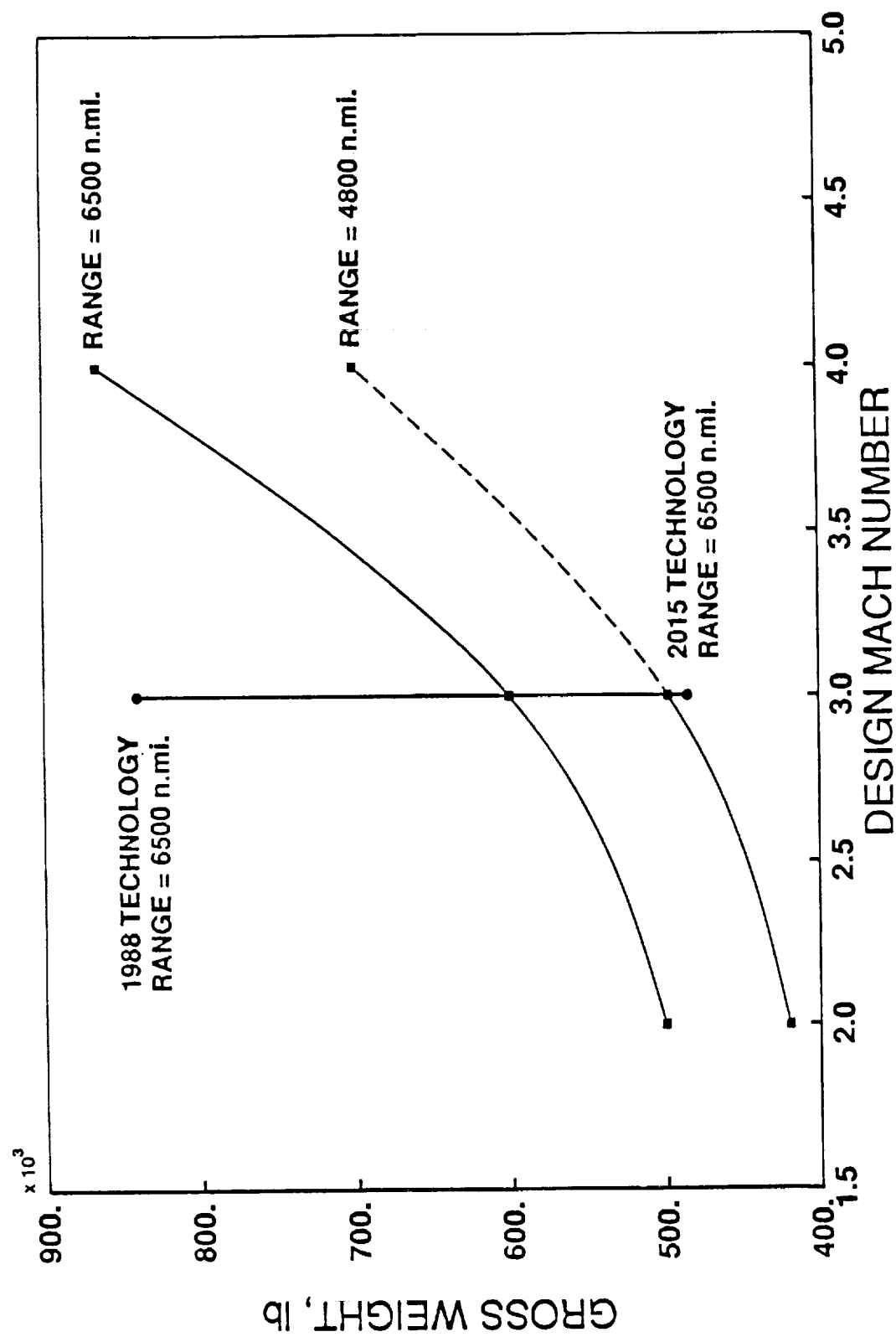
CONFIGURATION STUDIES 1987-1990



IMPACT OF DESIGN MACH NUMBER, RANGE, TECHNOLOGY

The resulting takeoff gross weights of the concepts over the Mach range from 2.0 to 4.0 are shown. At 6500 n.mi. range and utilizing an aggressive approach to year 2000 technology availability, the TOGW's vary from approximately 500,000 lbs. at Mach 2.0 to over 865,000 lbs. at Mach 4.0. (Stage III noise requirements are not fully met.) As Mach 2.0 is approached, the curve tends to flatten out and will probably increase slightly if lower Mach numbers are considered. Reducing range 26 percent to 4800 n.mi. tends to reduce TOGW about 16 percent (dashed portion of the curve from Mach 3.0 to 4.0 is extrapolated). The very large payoff of advanced technology to these type aircraft is indicated by the vertical line. At 6500 n.mi. range and Mach 3.0, using technology available in 1988, the TOGW would be over 840,000 lbs. A year 2000 technology airplane would be slightly over 600,000 lbs. and year 2015 technology availability could further reduce the TOGW to about 480,000 lbs. These weights reflect an assumption of that full achievement of goals associated with advanced technology are realized and tend to be lower than some HSR contractor weights, but the trends with range and technology availability match well whether the numbers are NASA or contractor generated.

IMPACT OF DESIGN MACH NUMBER, RANGE, TECHNOLOGY



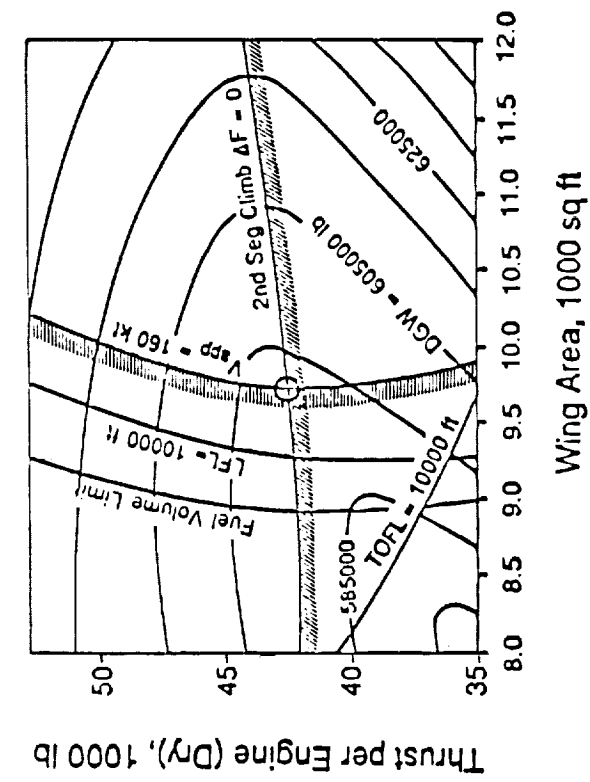
ENGINE AND WING SIZING

Mach 3.0 Concepts

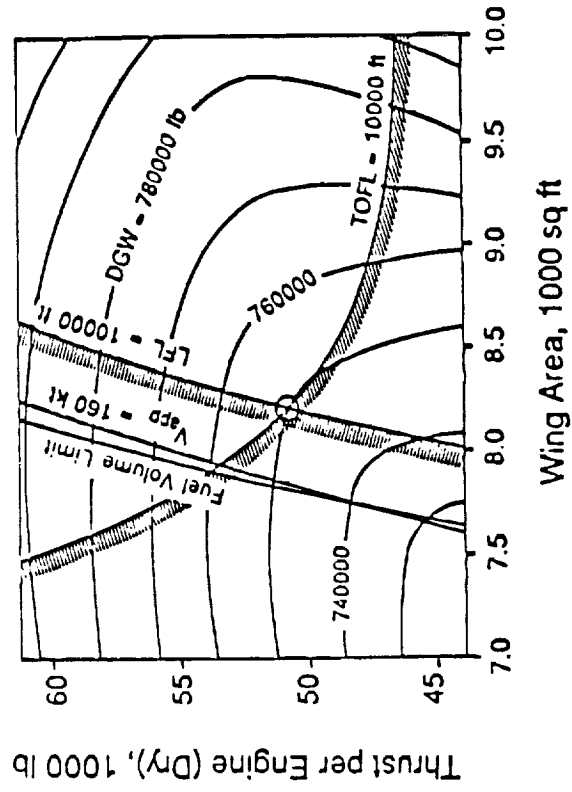
The Mach 3.0 variable sweep concept was examined in an attempt to improve the high subsonic cruise performance for overland flight as well as improve takeoff and landing performance. Unless successful low sonic boom concepts can be developed, a longer range HSCT will require good subsonic characteristics for its overland leg. Shown in this chart are the sizing thumbprints for the fixed wing and variable sweep concepts for a 6500 n.mi. all supersonic mission. The fixed wing concept sizes to about 600,000 lbs. by the requirements that approach speed with 3/4 fuel load be less than 160 knots and that second segment engine out climb gradient be met. Takeoff thrust-to-weight ratio is about .28 and wing loading 61 lbs./ft². The variable sweep airplane is sized to 750,000 lbs. and is constrained by landing field length and takeoff field length. Takeoff thrust-to-weight and wing loading are approximately .27 and 91 lbs/ft², respectively. Although the switch in sizing constraints indicate superior low-speed performance for the variable sweep airplane, its overall weight is greatly increased for an all supersonic mission due to difficulty in packaging the configuration to achieve a low drag concept and the additional weight associated with the pivot. The effect of sizing the two concepts for mixed subsonic/supersonic mission legs is shown on the next figure.

ENGINE AND WING SIZING

Mach 3.0 Concepts



Fixed Wing

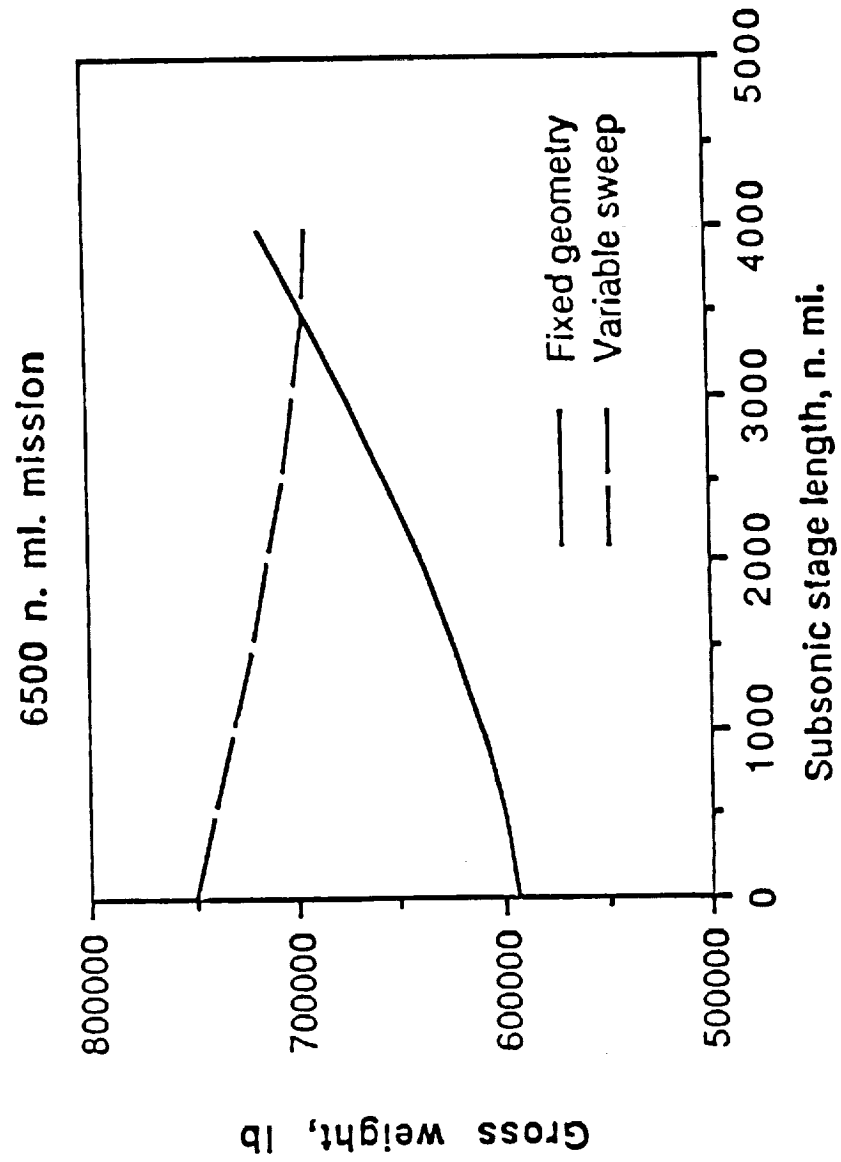


Variable Sweep Wing

EFFECT OF SUBSONIC SEGMENTS ON GROSS WEIGHT

The resizing of the fixed geometry and variable sweep concepts to meet 6500 n.mi. range with different subsonic stage lengths is shown in this figure. The improved subsonic aerodynamic efficiency of the variable sweep concept cannot overcome the initial large weight penalty until the airplane flies over half its mission at subsonic speeds. Although the variable wing sweep shows little promise for this Mach 3.0 application, it should not be completely dismissed. It may show more promise at a lower Mach number application and even more promise if altitude restrictions are imposed. Good low-speed performance with a wing sized for altitude-restricted supersonic cruise will be a difficult design situation with a fixed wing.

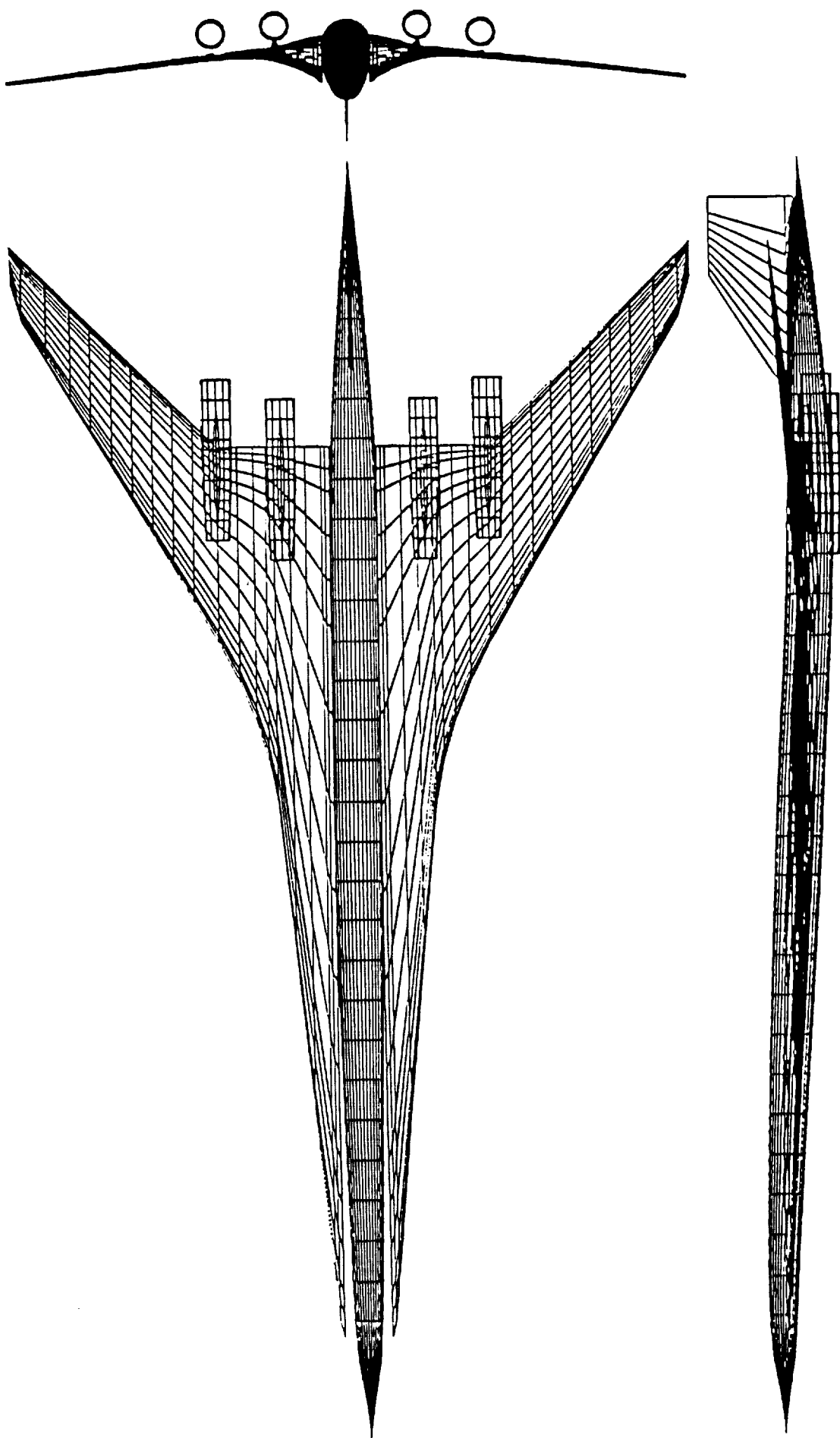
Effect of Subsonic Segments on Gross Weight



MACH 1.6 LOW-BOOM CONCEPT

The next two figures show the progress being made in designing low sonic boom concepts. This figure shows the numerical model of a Mach 1.6 concept currently under study. Low boom design requires long smoothly integrated wings so that the overall disturbance generated by lift and configuration volume meet the desired requirements for low boom. The configuration shown is the result of several iterations with emphasis on keeping wing aspect ratio in line with that of performance concepts without sonic boom considerations. The concept is currently undergoing a complete system analysis. Low speed stability and control will probably dictate the need for a canard which may pop out at subsonic speeds or may be fixed and simply be flown unloaded at supersonic speeds. The more detailed studies being conducted will provide the better systems analysis solutions in terms of volume utilization, weight, and drag and the resulting overall effect on mission performance to this and other issues.

MACH 1.6 LOW-BOOM CONCEPT

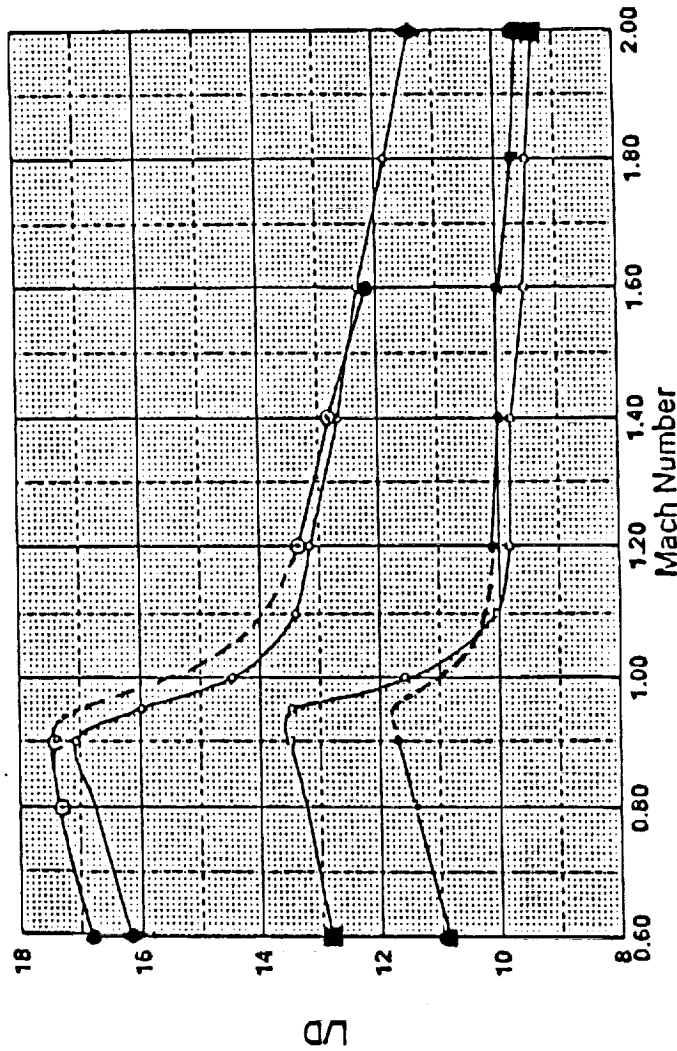


MAXIMUM L/D COMPARISONS

This figure shows the progress toward achieving low boom concepts with acceptable aerodynamic performance. The two earlier low boom concepts shown at the bottom suffered an across the speed range aerodynamic penalty in comparison to the configuration shown on the right which has no sonic boom requirements imposed. The low-boom configuration discussed in the previous figure (shown on the left) compares favorably with the configuration designed for aerodynamic performance. However, the caveat under the title that low-boom configuration is untrimmed gives a good indication of the work remaining before success is declared. Nevertheless, good progress is being made in achieving low sonic boom concepts with aerodynamic characteristics that compare favorably with concepts without sonic boom constraints.

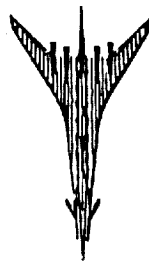
MAXIMUM L/D COMPARISONS

Aerodynamic Configuration Trimmed; Low-Boom Configurations Untrimmed.



S

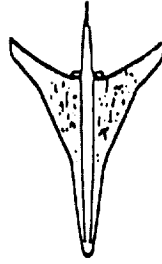
Low Boom III



$M_D = 1.6$



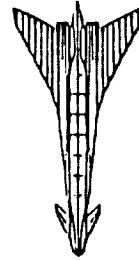
Aerodynamic



$M_D = 2.0$



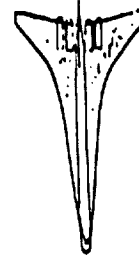
Low Boom II



$M_D = 2.0$



Low Boom I



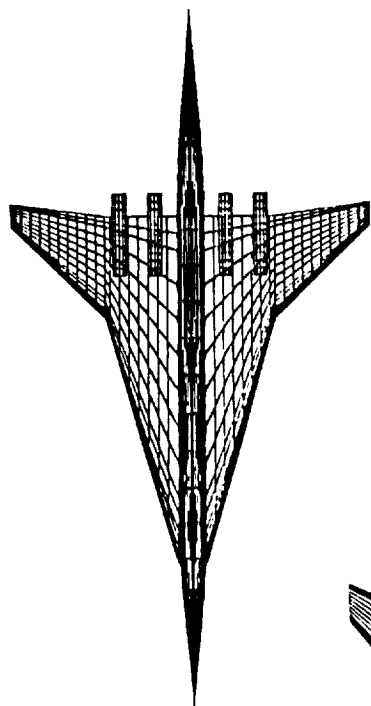
$M_D = 2.0$



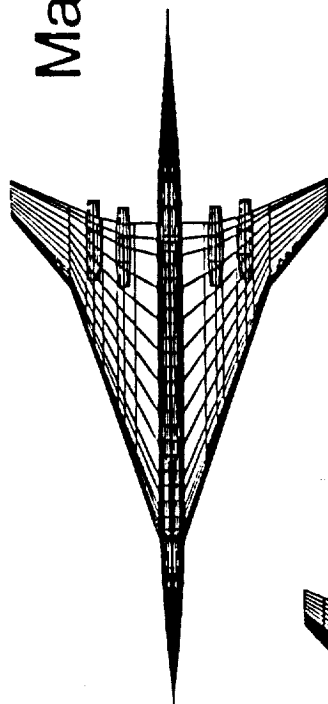
LANGLEY BASELINE CONCEPTS AS OF MAY 15, 1991

Late in 1990, the NASA Systems Integration Group began functioning and the aircraft systems studies entered a second phase. This group proposed tightly coordinated Ames/Langley/Lewis/Industry studies that would address a series of tasks to evaluate progress, recommend appropriate direction and emphasis changes in technology elements based on system-level payoffs and potential success assessments. Based on technical and economic assessment studies of HSCT's to date, Mach 2.4 was chosen as the primary focus for the High-Speed Research Program (HSRP) with Mach numbers 2.0 and 1.6 being backups in case of technology shortfalls. The current NASA Mach 1.6, 2.0, and 2.4 baseline concepts are shown in this figure. The concepts are not as highly integrated as the previously discussed concepts and will suffer a little in overall performance compared to a highly-integrated well-blended configuration. However, these generic concepts are easy to redesign or resize so as to evaluate technology and design options being proposed as part of HSRP. Highly integrated concepts tend to have little flexibility for other than small geometry changes. Several unanticipated problems arose in the design of the concepts. It was expected that the Mach 1.6 concept could have the inboard wing section unswept 12° and 13° with respect to the Mach 2.4 concept. However, the combination of lower wing sweep and lower Mach angle resulted in a configuration that was virtually impossible to area rule for wave drag, so wing sweep was maintained to get the desired aerodynamic efficiency. Also, the lower shock angle required the engines be spaced further apart to prevent mutual unstart. The Mach 2.4 concepts reflects some ongoing design trades with low-speed aerodynamics and structures, that have not been incorporated into the two lower Mach number concepts. All three concepts are generic in nature and will be used to answer such questions such as the fundamental trades between wing sweep, drag, low-speed aerodynamics, wing weight, stability and control, and so on. The consequences of cruise altitude restrictions will be examined on the 1.6 concept, as well as the application of advanced materials as a function of Mach number.

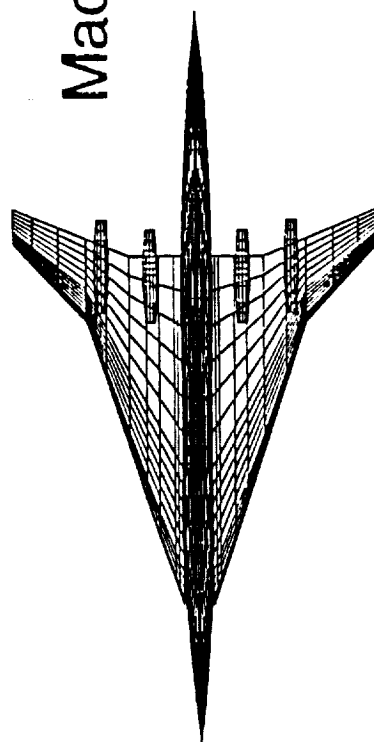
LANGLEY BASELINE CONCEPTS AS OF MAY 15, 1991



Mach 2.4



Mach 2.0

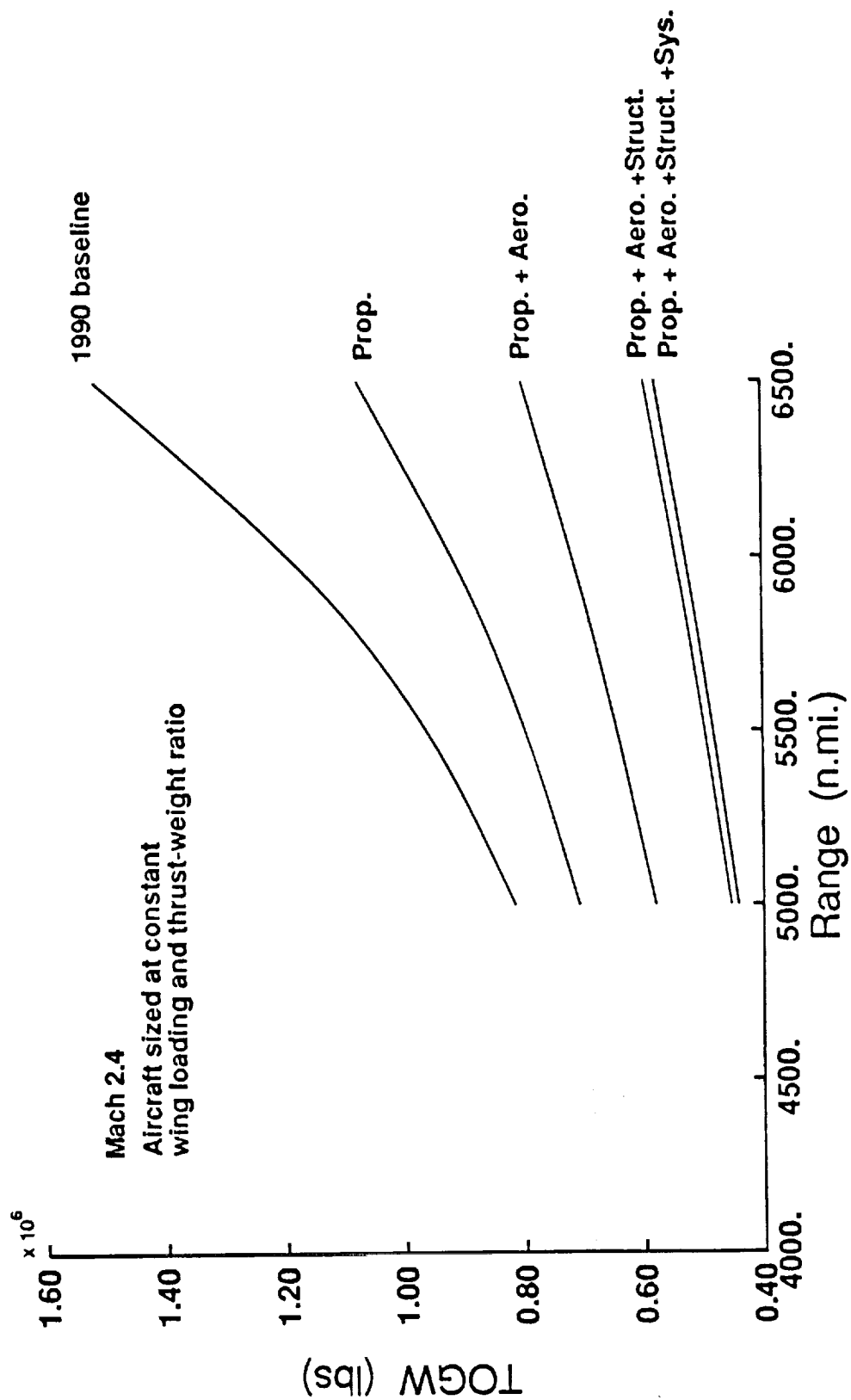


Mach 1.6

HSR TECHNOLOGY CHALLENGE

The payoff of meeting the technology goals established for the Phase II HSRP are shown in this figure for the Mach 2.4, 250 passenger concept. The individual technology goals associated with each discipline will be discussed in a following chart. The overall message is strong and clear that advanced technology has a tremendous payoff when applied to this type vehicle. Today's technology will barely support a reasonable size HSCT with a range of 5000 n.mi. If 100 percent success is achieved within the HSR technology program, the vehicle weight could be reduced approximately 45 percent at a constant range or be traded to achieve longer range with competitive sized aircraft. Cautionary note: These are sizing trends that indicate the maximum payoff. Detailed design of a configuration at each point will probably result in less than the maximum payoff indicated.

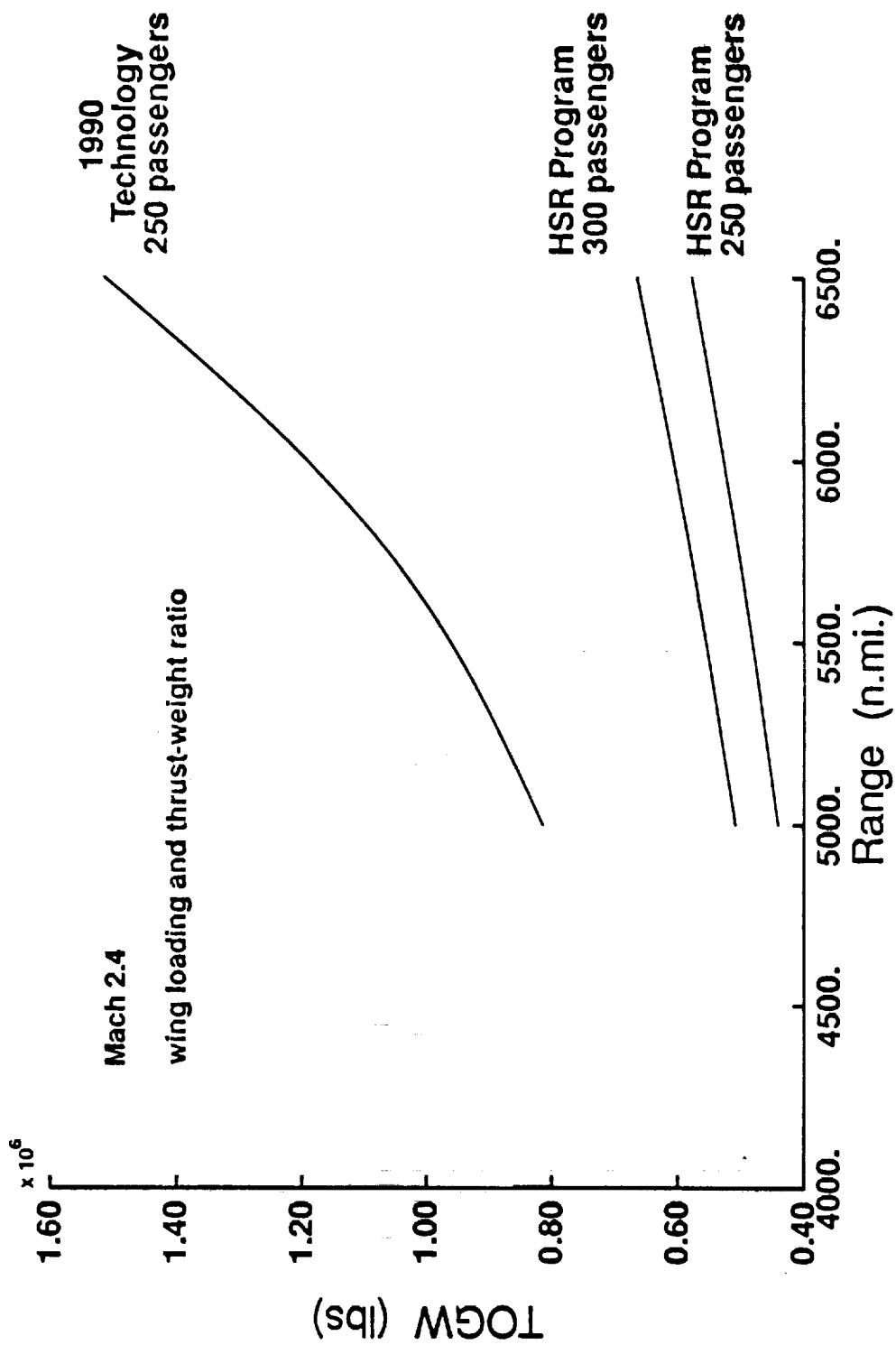
HSR TECHNOLOGY CHALLENGE



HSR TECHNOLOGY CHALLENGE

Since the objective of a commercial airplane is to achieve a satisfactory return on investment, a more likely payoff associated with advanced technology is shown. Instead of continuing to reduce weight, passenger payload and range will be increased. The figure shows that from an 800,000 lb., 5000 n.mi. range 1990 technology airplane, the full realization of the payoffs associated with Phase II HSR technologies would enable a range increase of 1500 n.mi. with a passenger increase of 50 and still reduce takeoff gross weight by over 10 percent. Longer range and more passengers translates directly into increased revenue passenger miles and increased return on investment.

HSR TECHNOLOGY CHALLENGE



HSR TECHNOLOGY OPPORTUNITIES

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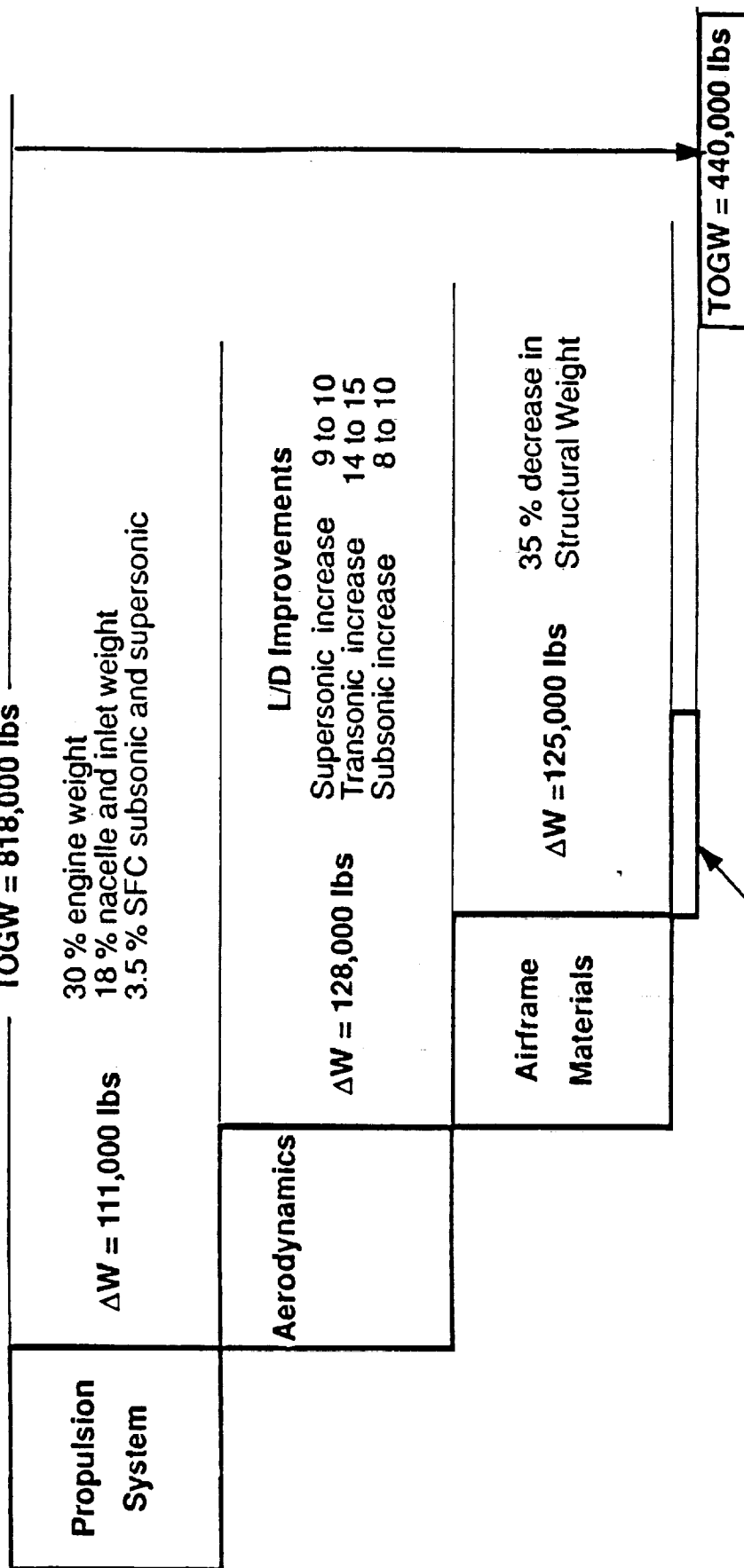
More details of the HSR technology opportunities are shown in this figure. The technology improvements shown are the expected result of the HSR Phase II Program or the adaptation of other applicable technologies such as propulsion materials from the Air Force's Integrated High Performance Turbine Engine Technology (IHPTET) Program. Again, these technology improvements are for a 2005 IOC relative to 1990 technology availability. An expected improvement of 30 percent in engine weight, 18 percent in nacelle and inlet weight, and 3.5 percent in SFC results in a takeoff gross weight reduction of 111,000 lbs. (14%). Achieving supersonic cruise, transonic and takeoff L/D's of 10, 15 and 10, respectively, further reduce TOGW by 128,000 lbs (16%). Advanced materials and structures which reduce the structural weight by 35 percent are worth 125,000 lbs. (15%) savings in TOGW. Synthetic Vision Systems to eliminate dropping the nose at takeoff and landing conditions and weight savings from advanced systems and controls save about 14,000 lbs. (2%) in TOGW. Weight savings associated with advanced controls, such as active controls for flutter and load alleviation, and integrated airframe/propulsion controls that reduce fuel burn have been bookkept under the discipline improved by the flight control system. The bottom line is that all disciplines have very significant contributions to make in developing an economically viable HSCT. Again, most of these huge weight savings would be traded for longer range and higher payload to increase economic competitiveness.

HSR TECHNOLOGY OPPORTUNITIES

Mach 2.4 cruise 5000 n.mi. range 250 passengers

1990 Technology

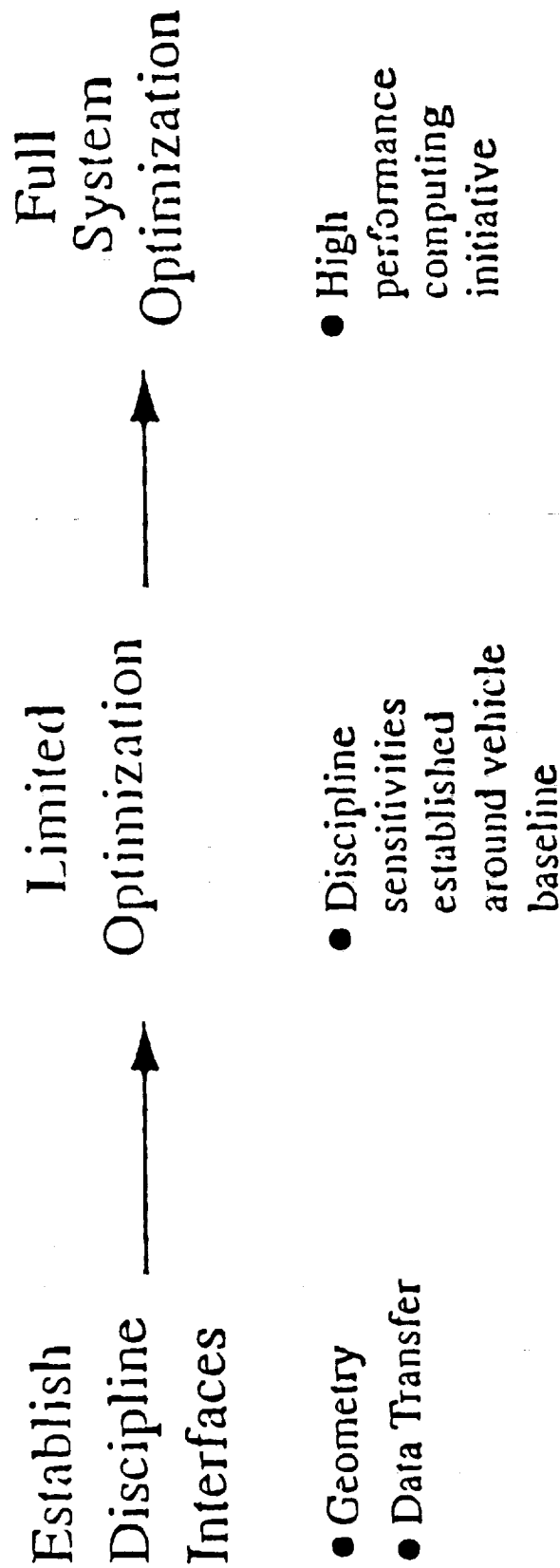
TOGW = 818,000 lbs



LONG-TERM MULTIDISCIPLINARY AIRFRAME INTEGRATION STRATEGY

Langley Research Center has established an interdisciplinary team to strengthen the multidisciplinary aspects of aircraft design and analysis. The vehicle focus of this team is the HSCT, although the resulting methodology and data management system will be applicable to other aircraft types. Experience indicates that methods development of this type are best accomplished and are applied if they are developed in response to a real programmatic need rather than generically. This figure indicates the long-term strategy for the High-Speed Airframe Integration Research (HiSAIR) project. The first step was to establish or reestablish discipline interfaces that are state-of-the-art in terms of that enabled by today's engineering workstations and computer networks. Two areas requiring much attention were the development of geometry methods that would permit rapidly modeling airplane concepts for first-order as well as higher order analysis by the various disciplines and the development of a data management system. Currently, modeling for higher order methods can take as long as two months, even starting with numerical models acceptable for first-order analysis. We think we can cut that time to one or two days. A data management system that permits data transfer between disciplines without an overhead burden on the discipline expert is being put together. The project is moving into the second phase of limited optimization. This phase will establish the methodology for rigorous optimization via discipline sensitivity derivatives for a baseline vehicle. The longer range (approximately 5 years) goal is to develop a system that permits full multidisciplinary coupling and optimization. Langley is anxious to interact with company aircraft design teams and advanced design organizations to enhance the value of this work. Again, the vehicle focus of HiSAIR is the HSCT and it is being used to develop the Mach 1.6, 2.0, and 2.4 NASA study concepts. In addition to strengthening discipline research, one result of HiSAIR will be a higher level of fidelity in Langley's vehicle systems studies.

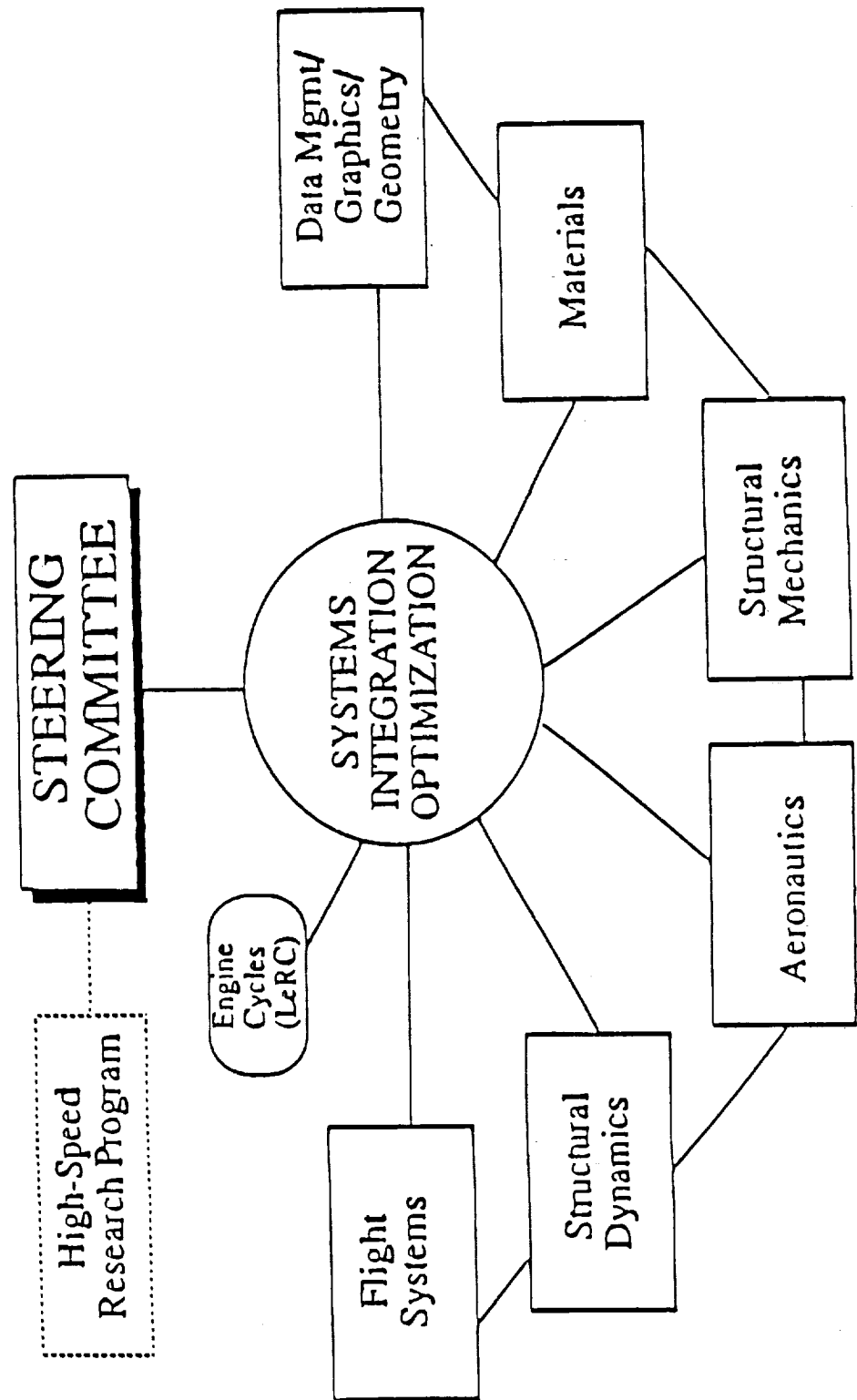
LONG-TERM MULTIDISCIPLINARY AIRFRAME INTEGRATION STRATEGY



HIGH-SPEED AIRFRAME INTEGRATION RESEARCH MANAGEMENT

The HiSAIR project cuts across four directorates at Langley and has geometric methods development in common with a fifth. A Steering Committee of Division Chiefs sets policy and direction. Systems integration and optimization as performed by the Vehicle Integration Branch, Advanced Vehicles Division, and the Interdisciplinary Research Office, Structural Dynamics Division, are the controls for the activity. Engines are supplied by Lewis Research Center, and eventually Lewis's efforts in propulsion system design methods and Langley's HiSAIR will be formally coupled. Discipline experts from the functional areas shown around the figure make up the HiSAIR team.

HIGH-SPEED AIRFRAME INTEGRATION RESEARCH MANAGEMENT



HIGH-SPEED AIRFRAME INTEGRATION RESEARCH

Status

The status of the HiSAIR activity is shown on this figure. In addition to the points on this figure, the real value of HiSAIR for Langley is the strengthening of disciplinary research within vehicle focus programs. This strengthening occurs through an understanding of the multidisciplinary application of technology to a vehicle system. Technology transfer and value is enhanced by research and data bases more in line with how the aircraft industry will eventually apply the research.

HIGH SPEED AIRFRAME INTEGRATION RESEARCH

STATUS

- Full Time Manager ; 30 Professionals (most part-time)
- Performed High Level Analysis of High-Speed Civil Transport
- High Priority on Developing Numerical Modeling Techniques
- Data Management System Coming Together
- Concurrent Development of Optimization Methods
- HiSAIR Being Used to Design In-House Baseline Concepts in Support of HSR Program

CONCLUDING REMARKS

SELF-EXPLANATORY

CONCLUDING REMARKS

- **EARLY HSCT STUDIES FOCUSED ON TURBOJET POWERED AIRCRAFT**
- **VARIABLE-SWEEP WING CONCEPT REQUIRES 50/50 SUBSONIC/SUPERSONIC TO PAYOFF FOR MACH 3.0 CONCEPT**
- **GOOD PROGRESS IN LOW-BOOM CONCEPTS**
- **CURRENT EMPHASIS ON “GENERIC” CONCEPTS TO FACILITATE TECHNOLOGY TRADES**
- **SYSTEMS STUDIES REQUIRED TO ANSWER “IS IT AN AIRPLANE YET?”**

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Session III. Atmospheric Effects

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Session III. Atmospheric Effects

Stratospheric Models and Measurements: A Critical Comparison
Dr. Ellis E. Remsberg, NASA Langley Research Center

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STRATOSPHERIC MODELS AND MEASUREMENTS: A CRITICAL COMPARISON

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Atmospheric Sciences Division
NASA Langley Research Center
Hampton, Virginia

First Annual High-Speed Research Workshop
Williamsburg, Virginia
May 14-16, 1991

INTRODUCTION

The stated objectives of the HSRP/Atmospheric Effects of Stratospheric Aircraft (AESA) initiative are to support research in the atmospheric sciences that will improve our basic understanding of the circulation and chemistry of the stratosphere and lead to (interim) assessments of the impact of a projected fleet of HSCT's on the stratosphere. Three model comparison workshops have been conducted, so far, in support of this goal; they occurred in 1987 at Ft. Myers Beach, Florida, and in 1988 and 1991 at Virginia Beach, Virginia. These workshops have been focused on the differences between models used to calculate the atmospheric effects of the proposed aircraft emissions. It is now possible to test these models against atmospheric data, and that is the goal for 1991.

OBJECTIVES

The charge to the Models and Measurements (M&M) Subcommittee of AESA is to (1) establish a standard set of atmospheric measurements that can be used to test the reliability of atmospheric chemistry models; (2) develop a method for evaluating model/data comparisons; and (3) direct the first major international stratospheric model/data comparison. We are currently addressing objective (1).

Data sets. The first subcommittee meeting, held in March 1991, was devoted to a discussion of the available data sets. A wide range of data already exist for our purposes. These data include ozone column or total ozone; multiple years of ozone, H₂O, CH₄, N₂O, and NO₂ distributions; column estimates of HNO₃, NO₂, HCl, and HF; satellite distributions of nitric acid; ATMOS and balloon profiles of various species, radioisotope, and aerosol distributions; and a "climatology" of polar stratospheric cloud (PSC) occurrences. Certain balloon and aircraft campaigns have obtained simultaneous data on many species and radicals, such that one can determine correlations for long-lived trace species, as well as perform checks on fast photochemical processes.

Multiple years of temperature, wind, and geopotential height data are available, from which one can characterize the state of the stratosphere for different seasons and locations. One can derive certain dynamical quantities from these data and they, in turn, can be used to diagnose the net transport in both the atmosphere and in models. It is expected that the Upper Atmosphere Research Satellite (UARS) will provide even more extensive data distributions, but they may not be publicly archived until late 1993. More importantly, new aircraft measurement campaigns will be conducted at a range of latitudes and altitudes in the lower stratosphere from 1992 through 1994. Those data should become available fairly quickly.

Many of the data sets already reside in an Upper Atmosphere Data Pilot (UADP) computer system at the NASA Langley Research Center. This repository will be supplemented with other data sets during 1991 upon the recommendation and assistance of the M&M subcommittee members. Output from the models will be gridded in formats that are

compatible with the data and will also be stored in the UADP. Species distributions from the models will be compared with the data distributions, and the subcommittee members will then assess the accuracy of those comparisons at a week-long meeting in January 1992.

Modeling activity. The selection of a set of model intercomparisons is being determined at this May 1991 Williamsburg subcommittee meeting. So far, a preliminary group of model studies has already been suggested. For three-dimensional models, they include simulations of the "present-day" stratosphere and a passive tracer study, and simulations of the "present-day" atmosphere, passive tracer or residence time studies with Carbon-14 and/or aerosols, the partitioning of NO_y and Cl_y chemical families, and an estimate of the chemical budget for ozone for two-dimensional models. There continues to be a need for model/model comparisons in the areas of photolysis calculations, chemical partitioning, and derived transport fluxes. Details of how to conduct the proposed model experiments will become final by mid-summer 1991. Criteria will also be developed at that time for making judgments about the quality of the results of each of the several model experiments.

Two reports are envisioned from this year-long activity. First, the subcommittee will prepare a UADP data report and include examples of and a statement about the quality, coverage, and length of the data sets. The second report will contain the results of those comparisons. It is believed that the need for model/data intercomparisons will continue after January 1992, as new data sets become available and models improve. It is hoped that the present M&M activity will lead to greater insight into those areas of needed model improvement, yet provide increasing confidence in the models to be used for the HSRP/AESA assessments that will come in succeeding years.

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Session III. Atmospheric Effects

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Previous Model Comparisons

Charles H. Jackman, NASA Goddard Space Flight Center

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PREVIOUS MODEL COMPARISONS

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First Annual High-Speed Research Workshop
Williamsburg, Virginia
May 14-16, 1991

1987 AND 1988 MODEL COMPARISON WORKSHOPS

The first model comparison was held at Ft. Myers Beach, Florida in January 1987. This meeting was attended by 26 participants from 5 nations representing 14 models. Issues discussed included 1) transport methodologies; 2) transport of nuclear test debris; 3) transport algorithms; 4) source gases; 5) NO_y , Cl_x , HO_x , and O_3 ; 6) photolysis rates; 7) diurnal averaging; and 8) rainout. The Upper Atmosphere Data Base at the NASA/Langley Research Center was first used at this meeting. The good interaction among the various modeling groups was the prime result of this comparison.

The second model comparison meeting was held at Virginia Beach, Virginia in September 1988. This meeting was attended by 35 participants from 7 nations representing 16 models. More real model-model intercomparisons were undertaken at the 1988 meeting and several topics were addressed including 1) photochemistry and radiation; 2) transport; 3) current atmosphere 1980; and 4) assessment runs: 1980 to 20xx. The Upper Atmosphere Data Base was used at the meeting for real-time intercomparisons.

Specific subjects discussed and intercompared in 1988 included 1) photolysis rates; 2) heating and cooling rates; 3) model circulations; 4) transport of an idealized tropospheric source gas, labeled X; 5) transport of an idealized time-dependent inert tracer, labeled Y; 6) transport of an idealized time-dependent stratospheric source gas (like ozone), labeled Z; 7) an informal comparison of model results versus observations; 8) an assessment of the "40 km ozone problem;" 9) column O_3 , HNO_3 , HCl , HF , and NO_2 ; 10) NO_y and Cl_x levels; 11) ratios NO/NO_2 , NO_2/HNO_3 , NO_x/NO_y ; 12) ratios Cl/ClO , ClO/Cl_x , ClO/HCl , $\text{ClONO}_2/\text{HCl}$; 13) ratios O/O_3 and OH/HO_2 and species H_2O_2 and H_2CO ; 14) distributions and lifetimes of N_2O , CH_4 , CFCl_3 , CF_2Cl_2 , CCl_4 , and CH_3CCl_3 ; 15) assessment runs of ozone perturbations from changing source gases; and 16) assessment runs of perturbed circulations and temperatures from changing source gases.

Model differences were documented and discussed at the 1988 meeting and several model errors were corrected as a result of the meeting. The NASA Conference Publication 3042, "Two-dimensional Intercomparison of Stratospheric Models," edited by C. H. Jackman, R. K. Seals, Jr., and M. J. Prather was published in 1989 as a result of the meeting. This document serves as a good reference for 1) model computations of photolysis rates, heating and cooling rates, and constituent distributions; 2) a post meeting analysis of a detailed intercomparison of thermal infrared cooling rates; and 3) model descriptions.

A couple of lessons were learned from this 1988 meeting: 1) not enough lead time for pre-meeting analysis of model results was allowed with too many comparisons being completed in real-time; and 2) too many comparisons were attempted which resulted in a document that was fairly comprehensive but not very conclusive. The models computed different values for photolysis rates even when O_3 and O_2 were fixed, thus more time should be spent at future model comparison meetings on radiation codes. Many model differences were determined at the 1988 meeting, however, there was little discussion on the validation of models. Criteria should be established in the future which can be used to validate models.

Session III. Atmospheric Effects

Model Capabilities, 3-D

Dr. William L. Grose, NASA Langley Research Center

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Session III. Atmospheric Effects

Model Capabilities, 2-D

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MODEL CAPABILITIES, 2-D

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First Annual High-Speed Research Workshop
Williamsburg, Virginia
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2-D MODEL CAPABILITIES

Two-dimensional (2-D) atmospheric models provide results for altitude versus latitude as a function of time and are developed primarily for two reasons: 1) to help understand atmospheric occurrences; and 2) to give assessments / make predictions of future changes in the atmosphere. Historically, the formulation of transport in 2-D models has been a difficult problem. Most current 2-D models have a transport that is either 1) an Eulerian mean circulation with large stratospheric eddy diffusion or 2) a residual (also called diabatic or Lagrangian) mean circulation which typically is accompanied with small stratospheric eddy diffusion. Because of the assumption of zonal averaging, 2-D models are primarily useful in making predictions of atmospheric changes of time-scales longer than a season. Although decadal atmospheric changes may be reasonably well represented with a 2-D model, the year to year changes which result from interannual transport differences, stratospheric warmings, semi-annual oscillations, or quasi-biennial oscillations may not be well represented in the stratosphere and troposphere.

PREVIOUS 2-D MODEL VALIDATION

The photochemistry in 2-D models has been validated in a variety of ways. 2-D model photochemistry has been investigated using constrained model simulations along with satellite and balloon measurements of photochemically controlled species. For example, 1) the 40 km O₃ problem was investigated by fixing NO₂, ClO, H₂O, CH₄, HNO₃, and O₃ to measurements and then computing the O₃ loss and production; and 2) HO_x (OH, HO₂, H₂O₂) species were computed from measured NO₂, ClO, H₂O, CH₄, HNO₃, and O₃ and compared to other measurements of HO_x. Other ways of validating the photochemistry in 2-D models include 1) a comparison of a measured versus a computed CH₃CCl₃ lifetime, which can validate the gross model distribution of OH; and 2) a comparison of measured versus computed solar flux in which the model computation uses O₃ which is fixed to measurements.

The transport in 2-D models has been investigated using photochemically inactive radioactive species and relatively photochemically inactive long-lived source gases. Radioactive species simulated in 2-D models include ¹⁴C, ⁹⁰Sr, ²³⁸Pu, ⁷Be, ¹⁰Be, and ³²P, among others. An "ideal" radioactive tracer should have 1) a half-life greater than 100 years so that radioactive decay is not a significant loss over the duration of the model simulation (typically a few years); 2) no attachment of the tracer to stratospheric aerosols which could lead to some transport by gravitational settling which is difficult to model; 3) no rainout loss in the troposphere which could significantly alter the tracer distribution in the upper troposphere and lower stratosphere; and 4) only loss at the ground. Of the radioactive tracers listed above, ¹⁴C is the only constituent to satisfy all the given conditions for an "ideal" radioactive tracer. Relatively photochemically inactive long-lived source gases whose losses are primarily through photolysis include N₂O, CFCl₃, CF₂Cl₂, and CCl₄. Other source gases which have been used to test 2-D transport include CH₄, CH₃Cl, and CH₃CCl₃.

Many minor constituents in the stratosphere such as NO_y , Cl_x , and O_3 are controlled by both photochemistry and transport, thus validation of model predictions of these species is much more difficult. Both profiles and columns of NO_y constituents have been used to test 2-D models. For example, there have been several constrained 2-D model computations. LIMS NO_2 and HNO_3 have been compared to model computed NO_2 and HNO_3 using a model constrained with measurements of N_2O , O_3 , CH_4 , and H_2O . Model simulated halogen-containing constituents (e.g., ClO , HCl , and HF) have been compared to measurements both in profile and column distributions.

Stratospheric model simulations are primarily of importance in the predictions of ozone distributions, both for the present-day and for the future. Ozone is affected photochemically by many constituents and also influenced by transport, thus a comparison of modeled distributions with measurements is often not very definitive. 2-D profile distributions of ozone, layers of ozone (10-1 mb, 100-10 mb, and 1000-100 mb), and total ozone (1000-0 mb) have all been compared to measurements. Since the prediction of total ozone is the most noticeable forecast of 2-D models, modeled total ozone is compared in great detail to observations. It is, however, possible to have a good simulation of total ozone as well as to have large differences between the simulated and measured 2-D ozone profile distributions.

Other tests for model validation include simulations of the atmospheric effects of solar proton events (SPEs) and simulations of HDO. There have been measured ozone decreases and NO increases as a result of SPEs, so model simulations of these constituents can be compared to observations. Such model predictions of SPE effects on the atmosphere require measured proton fluxes, which can then be used to predict NO_x and HO_x production and the associated ozone loss. About half of the H_2O in the stratosphere comes from tropospheric H_2O and about half from CH_4 . Since D (deuterium) comes mostly from deuterated methane (CH_3D), a computation of HDO compared with observations can be a good check on a model simulation of H_2O .

FUTURE 2-D MODEL VALIDATION

A model-model photolysis rate intercomparison needs to be done with fixed O_3 and O_2 . Any differences will be due to the radiative transfer procedures and not due to the photochemistry or transport. Other possible model-model intercomparisons include contrasting the partitioning of the constituents in the various families and comparing the transport fluxes of certain constituents at specific locations. Model-data intercomparisons should probably include a radioactive tracer such as ^{14}C , 2D distributions of NO_y , 2D distributions of ozone, total ozone, and the partitioning within the families of NO_y and Cl_y .

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Session III. Atmospheric Effects

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Quality of Existing Data Sets - Total Ozone and Chemical Species

Dr. Richard McPeters, NASA Goddard Space Flight Center; and Dr. Stephen R. Kawa, NOAA

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Session III. Atmospheric Effects

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Comparison of the Impact of Volcanic Eruptions and Aircraft Emissions on the Aerosol Mass Loading and Sulfur Budget in the Stratosphere

Dr. Glenn K. Yue and Dr. Lamont R. Poole, NASA Langley Research Center

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**COMPARISON OF THE IMPACT OF VOLCANIC ERUPTIONS AND
AIRCRAFT EMISSIONS ON THE AEROSOL MASS LOADING AND
SULFUR BUDGET IN THE STRATOSPHERE**

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Comparison of the Impact of Volcanic Eruptions and Aircraft Emissions on the Aerosol Mass Loading and Sulfur Budget in the Stratosphere

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Abstract

Data obtained by the Stratospheric Aerosol and Gas Experiment (SAGE) I and II were used to study the temporal variation of aerosol optical properties and to assess the mass loading of stratospheric aerosols from the eruption of volcanos Ruiz and Kelut. It was found that the yearly global average of optical depth at $1.0 \mu\text{m}$ for stratospheric background aerosols in 1979 was 1.16×10^{-3} and in 1989 was 1.66×10^{-3} . The eruptions of volcanos Ruiz and Kelut ejected at least 5.6×10^5 and 1.8×10^5 tons of material into the stratosphere, respectively. The amount of sulfur emitted per year from the projected subsonic and supersonic fleet is comparable to that contained in the background aerosol particles in mid-latitudes from 35°N to 55°N .

Introduction

It is recognized that the "background" aerosol particles in the lower stratosphere are supercooled sulfuric acid solution droplets composed of about 75% sulfuric acid by weight. Since these aerosols can directly and indirectly influence the radiation budget of the atmosphere and, thus, affect the climate, their properties have been of increasing concern. Based on measurements by optical particle counters over Laramie, Wyoming, during the period from 1971 to 1990, Hofmann (ref. 1) suggested that the background stratospheric sulfuric acid aerosol mass at northern mid-latitudes has increased by about 5% per year during the past 10 years. He later suggested that this increase of aerosol mass may be related to the increased emission of sulfur from aircraft (ref. 2). By considering the worldwide jet fuel consumption of $153 \times 10^9 \text{ kg}$ in 1987, and assuming the mass concentration of stratospheric aerosol is about $0.1 \mu\text{g m}^{-3}$ with a layer thickness of 5 km, he found that the total sulfur emission per year from airline traffic is about 65% of the required source strength for background aerosols. If this estimate is true, sulfur emissions from the continuously increasing airline traffic flight may greatly enhance the mass loading of aerosol particles in the stratosphere and perturb stratospheric temperature and ozone concentrations.

In this paper, we will address three questions: (1) Are background aerosol particles in the stratosphere increasing? (2) What is the effect of volcanic eruptions on the mass loading of aerosol particles in the stratosphere? (3) How does the amount of sulfur emitted from the proposed high-speed civil transport (HSCT) fleet compare with

other sources of sulfur in the stratosphere? Our results are based on the global measurements of aerosol particles measured by the Stratospheric Aerosol and Gas Experiment (SAGE) I and II (refs. 3 and 4). The calculation of the amount of sulfur from aircraft exhaust is based on the latitudinal distribution of fuel used by supersonic and subsonic aircraft (ref. 5).

Temporal Variation of Optical Properties of Stratospheric Aerosols Measured by SAGE I and II

SAGE I was launched on February 18, 1979, on the Application Explorer Mission-II (AEM-II) satellite. Its sensors measured the intensity of solar radiation traversing the Earth's limb during each sunrise and sunset event (approximately 15 each per day) encountered by the spacecraft in its orbit. The measured data were inverted to obtain profiles of aerosol extinction at 1.0 and 0.45 μm . Due to a power failure in the spacecraft, SAGE I measured only sunset events after May 1979 and stopped collecting data entirely in December 1981. SAGE II was launched on October 5, 1984, on the Earth Radiation Budget Satellite (ERBS) and is still operational. The SAGE II instrument is in a similar orbit to SAGE I and provides aerosol extinction profiles at 1.02 μm , 0.453 μm , and two other wavelengths.

In this study, the optical depth of stratospheric aerosol is defined as the integral of the aerosol extinction coefficient at 1.0 μm or 1.02 μm from an altitude of 2 km above the tropopause to an altitude of 15 km above the tropopause. The 2 km is used because the available tropopause heights are not necessarily derived from measurements made close to the location of our profiles, and high altitude clouds will occasionally occur at heights above the assumed tropopause height (ref. 6). The SAGE I and SAGE II measurements of mean hemispheric optical depth at 1.0 μm are shown in Figures 1(a) and 1(b), respectively.

As can be seen from Figure 1(a), the optical depths in the year 1979 for both hemispheres were quite constant at about 1.16×10^{-3} . After December 1979, the hemispheric optical depths began to increase gradually due to the eruption of volcanos Sierra Negra in November 1979, Mount St. Helens in May 1980, and Ulawun in October 1980. By the end of 1980, the level of volcanic debris in the Northern Hemisphere began decaying. However the eruptions of Alaid in April 1981 and Pagan in May 1981 ejected appreciable amounts of particles and gases into the stratosphere, resulting in the increase of optical depths after May 1981. The optical depths in November 1981 for the Southern and Northern Hemispheres were 2.3×10^{-3} and 2.4×10^{-3} , respectively.

At the beginning of 1985, the optical depths of the Southern and Northern Hemispheres were 6.9×10^{-3} and 8.6×10^{-3} , respectively. The several-fold increase of optical depth from the background value measured in 1979 is due to the presence of debris from El Chichon which erupted in April 1982. The optical depths vary

seasonally with a maximum in local winter and a minimum in local summer. The temporal decay of the level of debris from El Chichon eruption was interrupted by the eruption of Ruiz in November 1985 and the eruption of Kelut in February 1990. By the end of 1989, the optical depths of the Southern and Northern Hemispheres were 1.47×10^{-3} and 1.51×10^{-3} , respectively. The yearly averaged optical depths of the Southern and Northern Hemispheres for 1989 were 1.83×10^{-3} and 1.50×10^{-3} , respectively. If we regard the aerosol properties observed in 1989 as the new "background" aerosol properties, there is a 43% increase of aerosol optical depths from 1979 to 1989.

In order to study the change of aerosol size, we have also calculated the ratio of optical depth at 0.45 (or 0.453) μm to that at 1.0 (or 1.02) μm . This ratio is a measure of the column aerosol size; the smaller the ratio, the larger the size. The monthly optical depth ratios are averaged over each hemisphere and the results are shown in Figures 2(a) and 2(b). The SAGE I data shows a much larger month-to-month variation, possibly due to the fact that larger uncertainties are associated with the aerosol extinction at $0.45 \mu\text{m}$. Further observations are needed before any trend analysis of the aerosol size can be conclusive. However, the gradual increase in optical depth ratio for both hemispheres shown in Figure 2(b) does indicate that the effects of El Chichon are diminishing.

Mass Loading of Volcanic Aerosols

As mentioned in the previous section, there have been two major volcanic eruptions observed by SAGE II. The first increase in optical depth is identified to be due to the eruption of Ruiz (4.89°N , 75.37°W) on November 13, 1985, and the second increase in optical depth is identified to be due to the eruption of Kelut (7.93°S , 112.31°E) on February 10, 1990. The temporal variation of optical depth for latitude bands in the tropical region from 20°S to 20°N , where these two volcanos are located, is shown in Figure 3. The dramatic increase of optical depth after November 1985 and February 1990 is obvious in this figure. In order to estimate the mass loading of volcanic aerosols we have used the corresponding SAGE II water vapor data to deduce aerosol composition and the multi-wavelength aerosol data profile to deduce aerosol size (ref. 7). From aerosol composition and size distribution, the mass loading for each latitude band and month is calculated. The mass column density is obtained by integrating the mass density from a height of tropopause +2 km to a height of tropopause +15 km. The mass column density for latitude bands from 20°S to 20°N is shown in Figure 4. The global mass loading of stratospheric aerosols can easily be obtained by integrating the aerosol mass in each latitude band, and the results are shown in Figure 5(a).

It can be seen that after November 1985, the aerosol mass loading began to increase and reached a peak value in February 1986. The difference of aerosol mass loading in February 1986 and that in November 1985 was 5.6×10^5 metric tons. We

assume this is the amount of material ejected into the stratosphere by volcano Ruiz even though the actual amount should be higher since we are calculating only from a height of tropopause +2 km upward. The amount of material ejected by volcano Kelut was much less and was concentrated in tropical regions. We found it hard to estimate the amount of material ejected by Kelut in Figure 5(a) because the fluctuation of mass loading in high latitudes at the beginning of 1990 was comparable to that in low latitudes due to this volcanic eruption. The mass loading of aerosol particles in the stratosphere from 40°S to 40°N is shown in Figure 5(b). The difference in mass loading between January 1990 and March 1990 is 1.8×10^5 tons. In order to compare the strength of different volcanic eruptions and to assess the impact of volcanic eruption on the sulfur budget in the stratosphere, we have listed the estimates of mass loading from different volcanos in Table 1. In addition, the mass loading of 1979 background aerosols (ref. 6) and the mass loading of 1989 background aerosols obtained from Figure 5(a) are also listed. Both the Mount St. Helens and Ruiz eruptions ejected amounts of aerosol material close to the amount of background aerosols.

Table 1
Estimate of Aerosol Mass Loading in the Stratosphere

Date	Volcano or Background	Location	Mass Loading (10^5 tons)	Reference
1979	Background		5.7	6
1989	Background		7.5	This study
3/17/63	Agung	8.4°S, 115.5°E	160	8
			300	9, 10
10/10/74	Fuego	14.5°N, 90.9°E	60	9, 10
			30	11
1/22/76	St. Augustine	59.4°N, 153.4°W	6.0	10
4/17/79	La Soufriere	13.3°N, 61.2°W	0.023	12
11/13/79	Sierra Negra	0.8°S, 91.2°W	1.6	6
5/18/80	St. Helens	46.2°N, 122.2°W	5.5	6
10/7/80	Ulawun	5.0°S, 151.3°E	1.8	6
4/27/81	Alaid	50.8°N, 155.5°E	3.0	6
5/15/81	Pagan	18.1°N, 145.8°E	2.0	6
4/4/82	El Chichon	17.3°N, 93.2°W	200	13
			120	14
			101	15
11/13/85	Ruiz	4.9°N 75.4°W	5.6	This study
2/10/90	Kelut	7.9°S, 112.3°E	1.8	This study

Estimate of the Impact of Subsonic and Supersonic Aircraft Exhaust on Sulfur Budget

Aerosol particles in the stratosphere are formed, in large part, from precursor sulfur-bearing gases. Carbonyl sulfide (OCS) and sulfur dioxide (SO₂) are the most prominent precursors. Concentration of other sulfur-bearing gases, including carbon disulfide (CS₂) and hydrogen sulfide (H₂S), are too small to be of any direct influence on the formation and properties of sulfate particles in the stratosphere. Both carbonyl sulfide and sulfur dioxide will be oxidized through complex processes to form sulfuric acid (H₂SO₄) which directly affects the properties of sulfate particles (ref. 16). The concentration of OCS is about 0.3 to 0.5 ppbv at altitudes of about 15 km and rapidly decreases at higher altitudes (refs. 17 and 18). The concentration of SO₂ is about 0.05 ppbv at 15 km and decreases to 0.01 ppbv at 30 km (ref. 16). The concentration of H₂SO₄ has been deduced using mass spectrometer measurements of stratospheric ions. The results indicated that H₂SO₄ concentration is about $1.7 \times 10^5 \text{ cm}^{-3}$ in most parts of the lower stratosphere and it increases rapidly to 10^7 cm^{-3} near 34 km (refs. 19 and 20). The calculated global amounts of sulfur contained in these species in the lower stratosphere from 15 km to 30 km are listed in Table 2.

Also listed in Table 2 are the amount of sulfur in the 1979 and 1989 background aerosols and aerosols from the eruption of St. Helens and Ruiz. We assume that stratospheric aerosols are composed of approximately 75% H₂SO₄ and 25% H₂O. Our estimate of sulfur for 1979 background aerosol is more than twice the value ($6.25 \times 10^7 \text{ kg}$) estimated by Hofmann. The reason is that he assumed an aerosol layer of 5 km thickness and we integrated aerosol data from a height of about 15 km to 30 km.

In the late 1980s, there has been renewed commercial interest in developing supersonic aircraft, now denoted as high-speed civil transports, or HSCTs. It is suggested that an economically feasible fleet size is about 500 aircraft, and it is estimated that the supersonic fleet will consume fuel during cruise at a rate of $70 \times 10^9 \text{ kg/year}$. The ideal cruise altitude depends on the Mach number which varies from about 15.8 km at Mach 1.6 to about 22.8 km at Mach 3.2. Since most of the flights will be in mid-latitudes, we assume all the supersonic aircraft exhaust reaches the stratosphere. For the subsonic fleet, the impact is represented by emissions at two cruise altitudes: 22,000-32,000 ft and 32,000-42,000 ft. The assumed fuel consumptions are $17 \times 10^9 \text{ kg/year}$ and $152 \times 10^9 \text{ kg/year}$, respectively. Depending on the flight altitude and latitude, some of the subsonic flights will be in the stratosphere. If we follow Hofmann's argument that 1/6 of the flights at 32,000-42,000 ft are in the stratosphere and 1/4 of the exhaust from tropospheric flights will be transported into the stratosphere through dynamic processes, then 9/24 of the exhaust from subsonic jets will reach the stratosphere. The emission index for SO₂ is 1.0 gm per 1.0 kg of fuel. The amounts of sulfur in the SO₂ from the exhaust of subsonic and

supersonic fleets per year are also listed in Table 2. Since a lifetime of 1 year is typical of volcanic stratospheric aerosols, we assume that the sulfur from aircraft engines will stay in stratosphere for 1 year.

Table 2
Amount of Sulfur in the Stratosphere

Source	Amount (10^7 kg)
Background OCS	17.4
Background SO ₂	2.6
Background H ₂ SO ₄	0.03
Background Aerosol (1979)	14.0
Background Aerosol (1989)	18.3
St. Helens Aerosol	13.5
Ruiz Aerosol	13.7
SO ₂ in Exhaust from Subsonic Fleet	2.9
SO ₂ in Exhaust from Supersonic Fleet	3.5

It can be seen that the SO₂ from the aircraft exhaust is comparable to the background SO₂ concentration. It should be noted that most commercial flights are in the 30°N - 50°N corridor. In these regions the yearly exhaust of SO₂ from aircraft is higher than the background value. We used the SAGE II data sets to calculate the average mass loading of aerosol particles in each latitude band for 1989. The latitudinal distributions of sulfur from the exhaust of the subsonic fleet at 32,000-42,000 ft and from the exhaust of the supersonic fleet are also calculated. The ratios of these values to the sulfur in the 1989 aerosol particles are plotted in Figures 6(a) and 6(b).

Our results show that sulfur from the exhaust of the subsonic fleet at 35° N is about 92% of that from sulfate particles. At 45°N, the exhaust of the supersonic fleet is about 82% of that from sulfate particles. Even at other latitudes between 25°N and 55°N, the amount of sulfur exhausted from aircrafts is comparable to that in the background aerosols. Since most of the flights are at altitudes below 22 km and our estimation of the background sulfur is integrated from 15 km to 30 km, the amount of sulfur from engine exhaust is more than that from background aerosols in lower altitudes. Also, the appreciable increase in the amount of sulfur in the lower stratosphere from aircraft engine exhaust may increase both the number and sizes of aerosol particles in the stratosphere. The effect on northern mid-latitudes may be similar to that after a moderate volcanic eruption such as Mount St. Helens and Ruiz. If airline traffic is doubled for a period of years and the engine exhaust remains in the stratosphere for more than a year, stratospheric temperature and ozone concentrations may be perturbed appreciably. A more accurate estimate requires detailed study of the dynamical and chemical processes involving sulfur compounds in the stratosphere.

Conclusions

Based on stratospheric aerosol properties observed by the SAGE I and SAGE II experiments and a realistic estimate of exhaust from future subsonic and supersonic aircraft fleets, we conclude:

- (1) There is a 43% increase in optical depth observed by SAGE II in 1989 relative to SAGE I in 1979. Debris from volcanic eruptions and aircraft exhausts may contribute to this increase in optical depth. Unfortunately, we have not had a chance to observe the optical properties of aerosol particles for one or two years without an eruption due to the Kelut eruption in early 1990. Further observations are needed before any trend analysis can be conclusive or before the relative importance of various sources can be assessed.
- (2) In general, the mass loading in the stratosphere decreased from 1985 to 1990, which indicates the diminishing influence of El Chichon material. However, the decay was interrupted by the eruption of Ruiz in November 1985, and the eruption of Kelut in February 1990. The amount of material ejected into the stratosphere by Ruiz was about 5.6×10^5 tons, which is equal to the 1979 global mass loading of background aerosols. The amount of material ejected into the stratosphere by Kelut was only about 1.8×10^5 tons.
- (3) If the lifetime of sulfur from aircraft exhausts is 1 year, typical of volcanic stratospheric aerosol, the amount of sulfur from aircraft exhaust is comparable to that in the ambient aerosols at latitudes from 30°N to 50°N where most commercial airline flights take place. The increase in the amount of sulfur in the stratosphere due to aircraft exhaust may equal that of a moderate volcanic eruption. If airline traffic continues to increase, aerosol mass loading may reach a level that will perturb stratospheric temperature and ozone.

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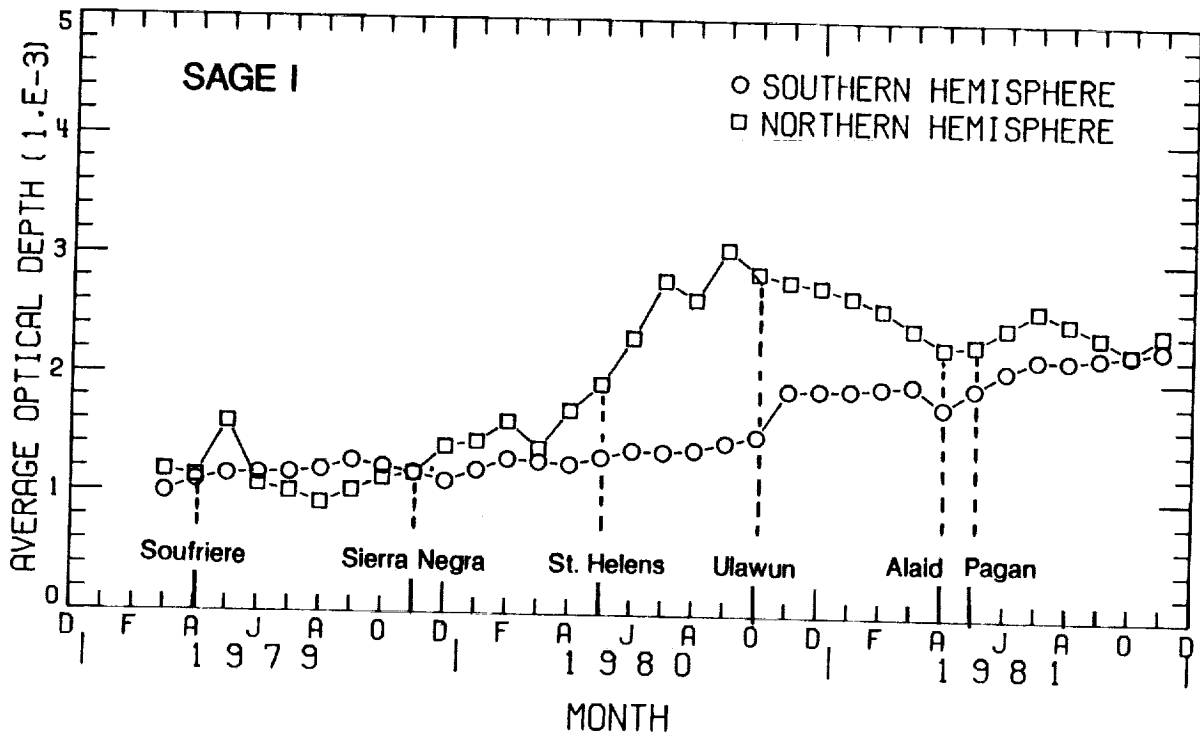


Figure 1(a)

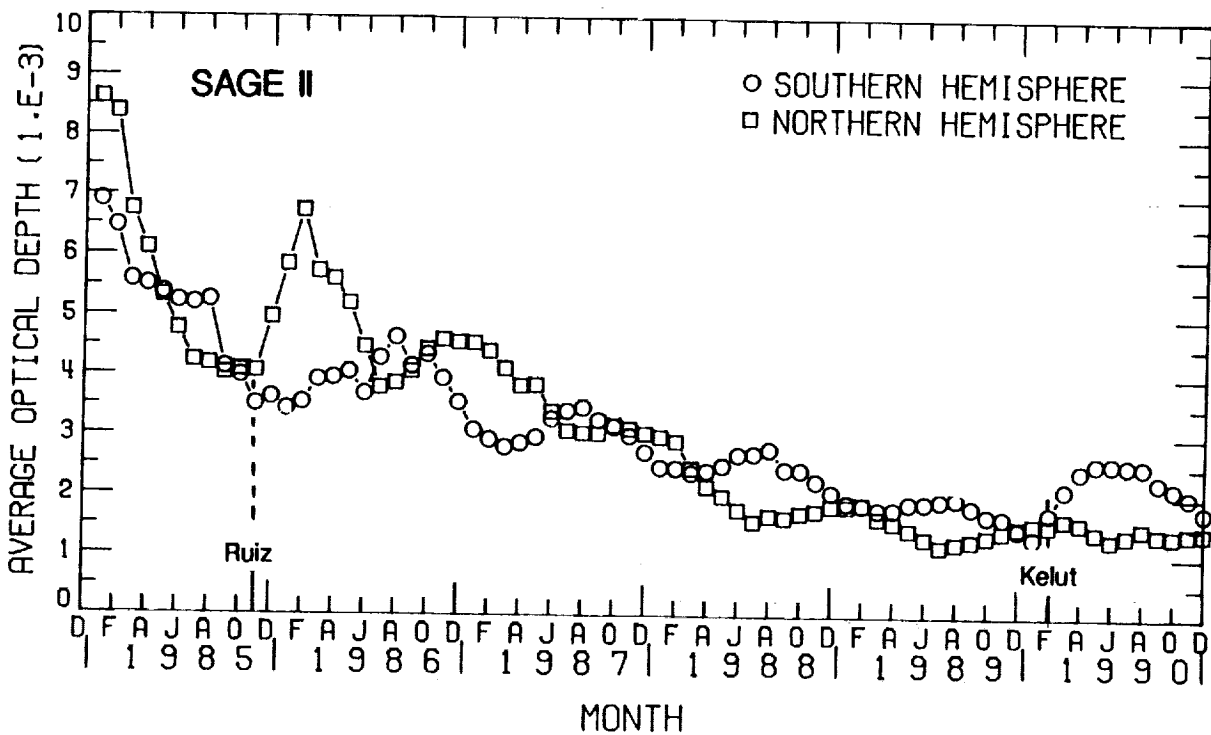


Figure 1(b)

Figure 1. Temporal variation of optical depth at 1.0 micron averaged over latitude in the Southern Hemisphere and the Northern Hemisphere.
(a) from 1979 to 1981, measured by SAGE I;
(b) from 1985 to 1990, measured by SAGE II.

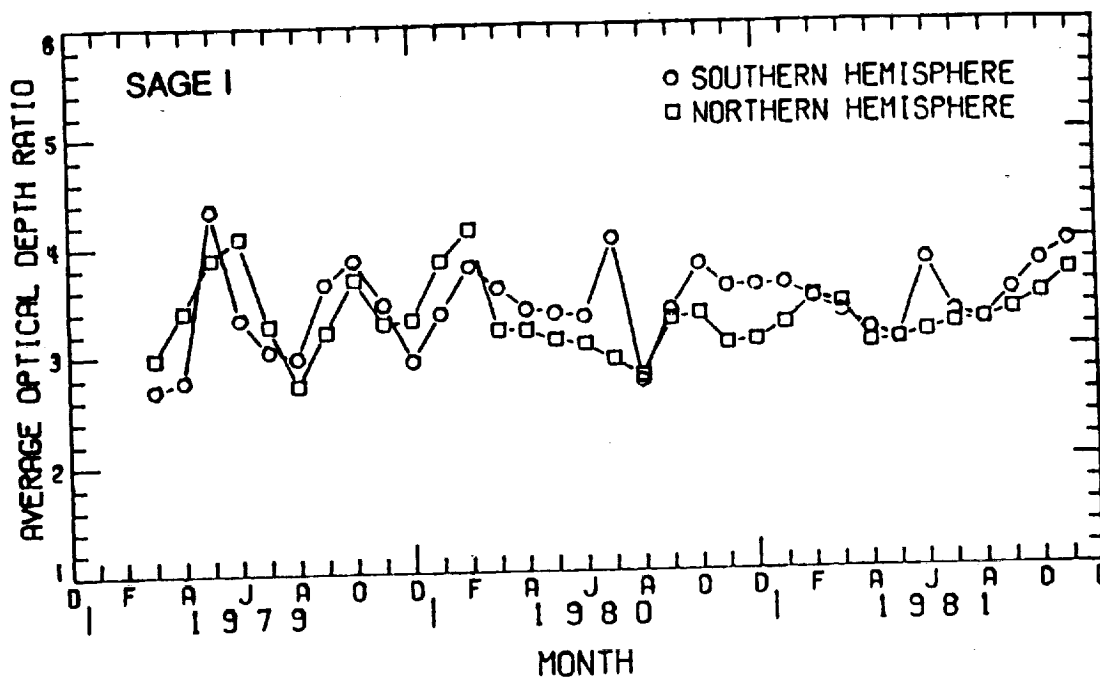


Figure 2(a)

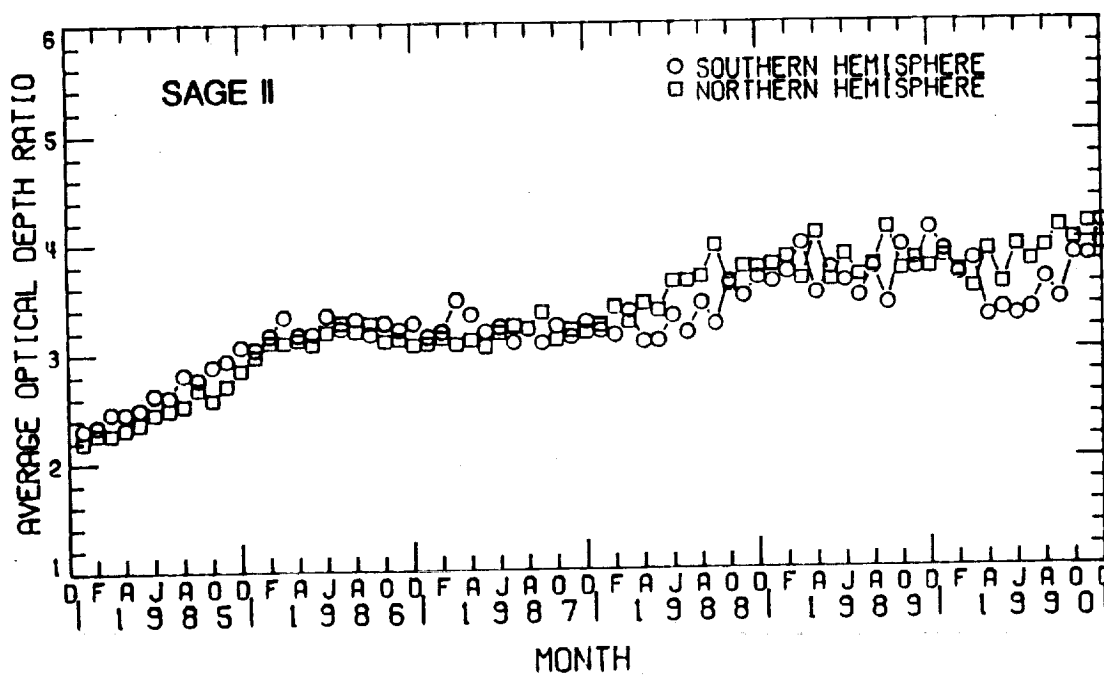


Figure 2(b)

Figure 2. Temporal variation of the ratio of optical depth at $0.45 \mu\text{m}$ to optical depth at $1.0 \mu\text{m}$ averaged over latitude in the Southern Hemisphere and Northern Hemisphere.

(a) from 1979 to 1981, measured by SAGE I;
(b) from 1985 to 1990, measured by SAGE II.

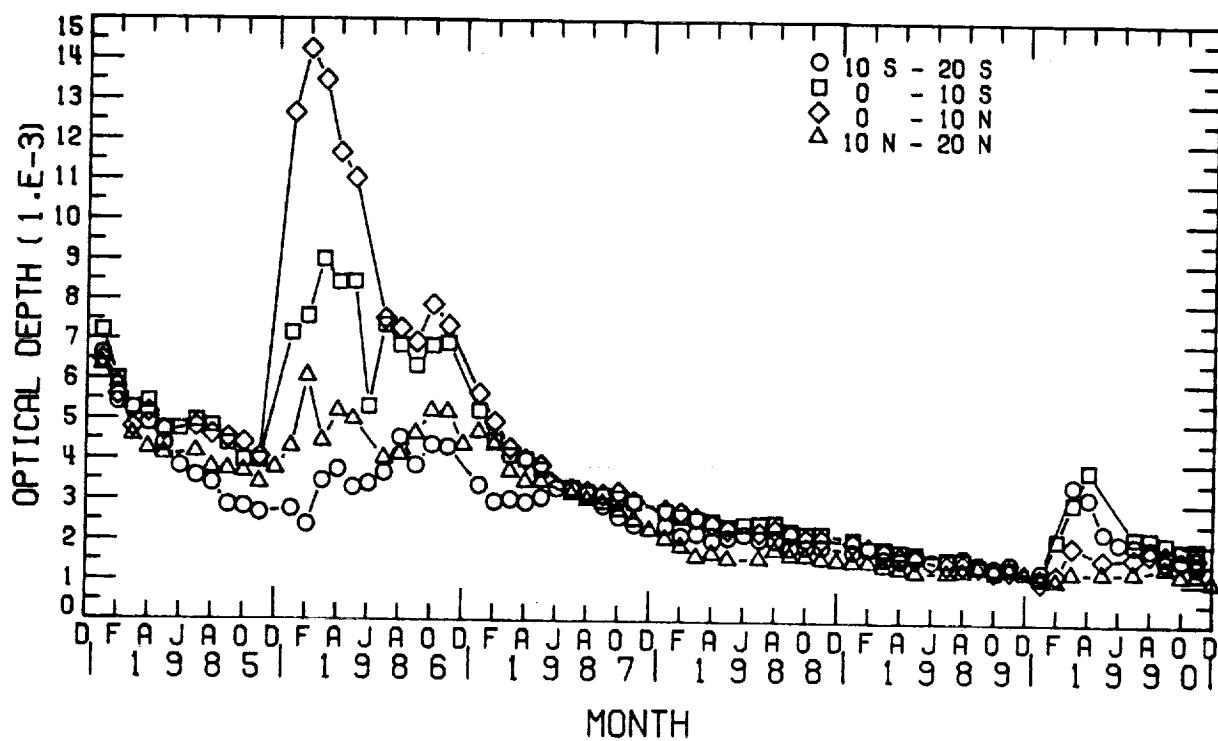


Figure 3. Temporal variation of optical depth at $1.02 \mu\text{m}$ measured by SAGE II from 1985 to 1990 for latitude bands from 20°S to 20°N .

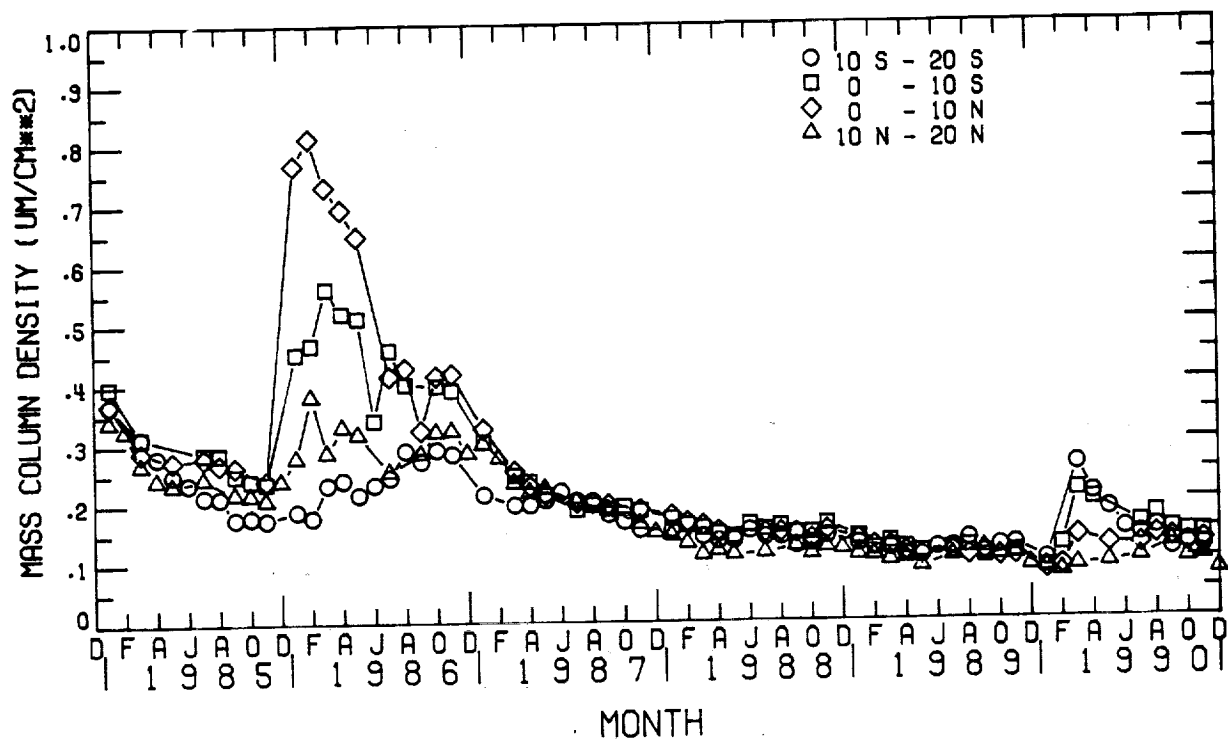


Figure 4. Temporal variation of mass column density deduced from SAGE II multiwavelength data from 1985 to 1990 for latitude bands from 20°S to 20°N.

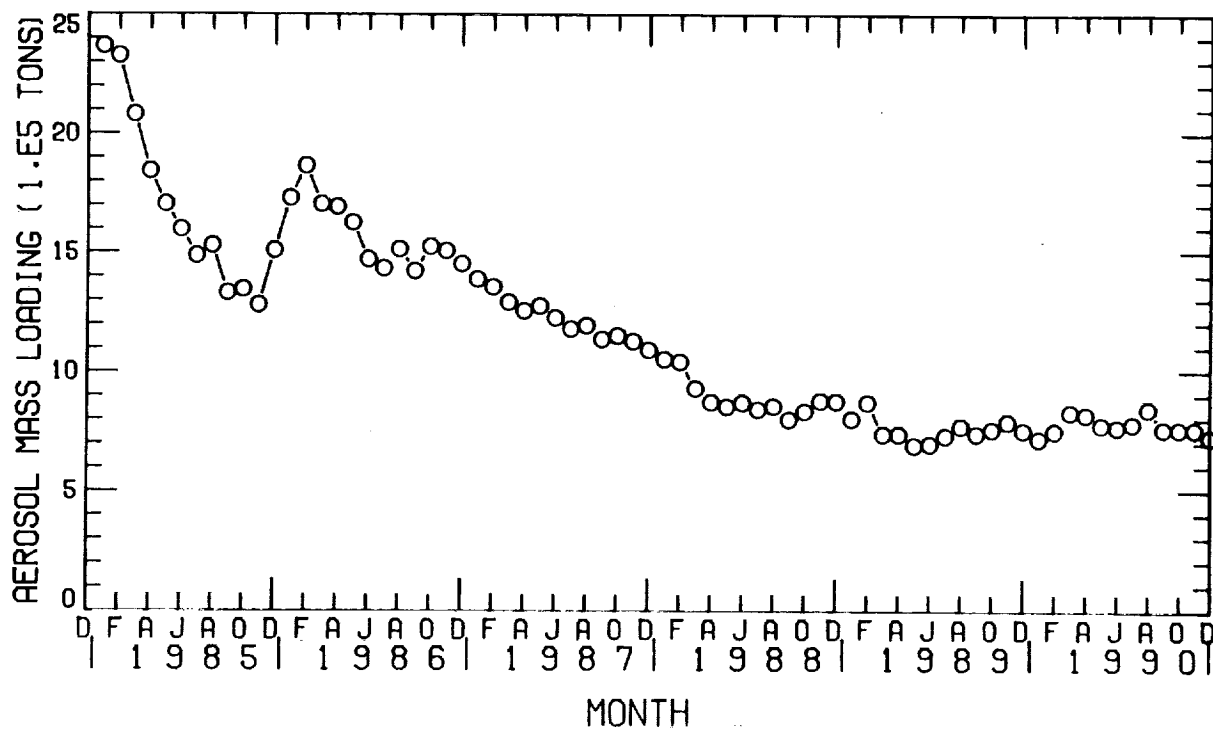


Figure 5(a)

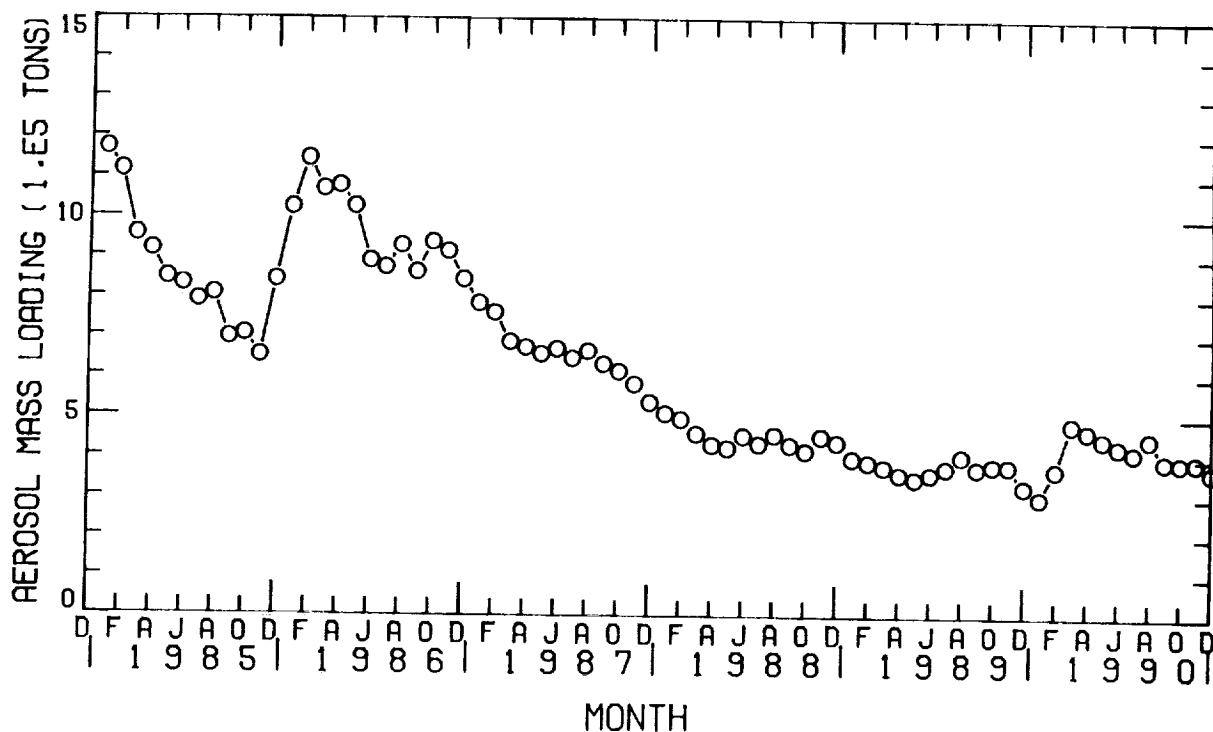


Figure 5(b)

Figure 5. Temporal variation of total mass loading for aerosols in the stratosphere.

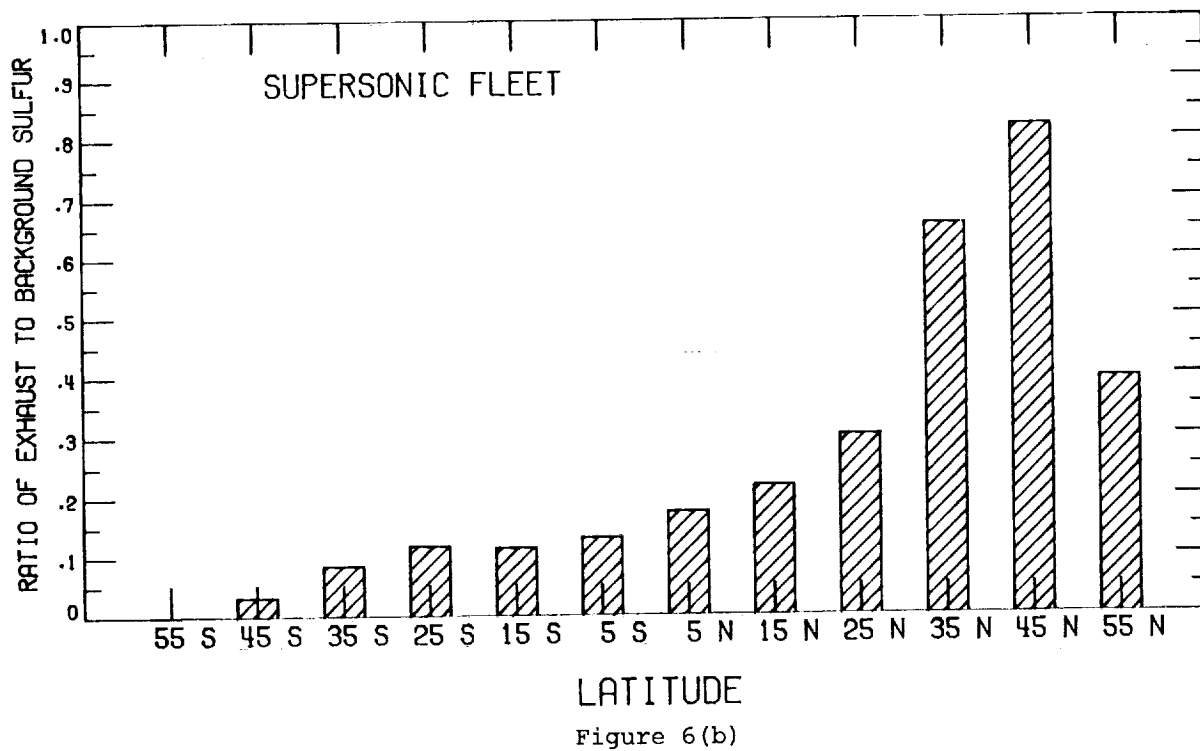
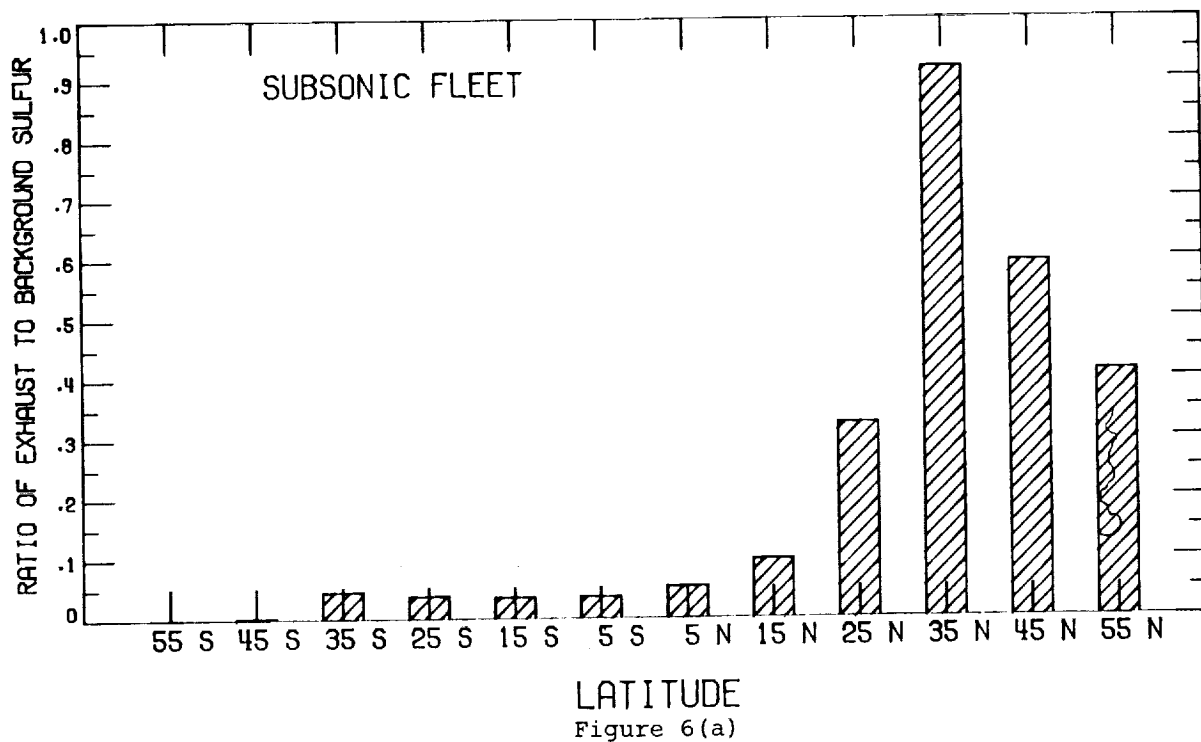


Figure 6. Latitudinal distribution of the ratio of sulfur in aircraft exhaust to that in the 1989 background aerosol particles.
 (a) Subsonic fleet;
 (b) Supersonic fleet.

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Session III. Atmospheric Effects

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High Resolution Infrared Datasets Useful for Validating Stratospheric Models
Curtis P. Rinsland, NASA Langley Research Center

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HIGH RESOLUTION INFRARED DATASETS
USEFUL FOR VALIDATING STRATOSPHERIC MODELS

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INTRODUCTION

An important objective of the High Speed Research Program (HSRP) is to support research in the atmospheric sciences that will improve our basic understanding of the circulation and chemistry of the stratosphere and lead to an interim assessment of the impact of a projected fleet of HSCTs (High Speed Civil Transports) on the stratosphere. As part of this work, critical comparisons between models and existing high-quality measurements are planned. These comparisons will be used to test the reliability of current atmospheric chemistry models. In this paper, two suitable sets of high-resolution infrared measurements are discussed.

ATMOS/SPACELAB 3 DATASET

The ATMOS (Atmospheric Trace Molecule Spectroscopy) experiment was designed to obtain 0.015-cm^{-1} resolution infrared solar occultation spectra of the atmosphere from which the vertical distributions of a large number of minor and trace molecular constituents of the upper atmosphere could be retrieved. The experiment was flown for the first time in the spring of 1985 as part of the Shuttle Spacelab-3 mission. Nineteen complete atmospheric occultations were recorded, twelve sunsets between latitudes of 25°N and 32°N , and seven sunrises between 45°S and 48°S latitude, on April 29 to May 1, 1985. For an overview of the ATMOS experiment and the results of the Spacelab 3 mission see the paper by Farmer (ref. 1).

The profiles for several dozen atmospheric constituents and pressure and temperature have been retrieved from the ATMOS middle atmosphere data. Because the spectra were recorded with broadband filters, chemically linked molecular species were often measured simultaneously, thus providing a unique opportunity to study the partitioning within key chemical families. The ATMOS/Spacelab 3 results are reviewed below. References which give the retrieved profiles and their uncertainties are cited.

Chlorine and Fluorine Budgets. Stratospheric profiles of 11 chlorine- and fluorine-containing source, sink, and reservoir molecules were derived from the Spacelab 3 measurements. The molecules are CCl_2F_2 (chlorofluorocarbon 12), CCl_3F (chlorofluorocarbon 11), CHClF_2 (chlorofluorocarbon 22), CCl_4 , ClONO_2 , HCl , HF , CF_4 (chlorofluorocarbon 14), COF_2 , CH_3Cl , and SF_6 . Results for the source gases have been reported by Zander et al. (ref. 2). Measurements of the sink gases were reported by Raper et al. (ref. 3). Recently, the profiles of HCl , HF , and ClONO_2 have been revised based on improvements in the spectroscopic database and the processing of the ATMOS spectra (ref. 4). The identification and results for SF_6 are reported in ref. 5.

Odd Nitrogen Budget. Profiles of the following odd nitrogen molecular species were derived from the Spacelab 3 measurements: NO , NO_2 , HNO_3 , HO_2NO_2 , N_2O_5 , and ClONO_2 . The analysis included normalized factors that correct for the rapid diurnal variations of NO and NO_2 at sunrise and sunset. These factors were computed with a photochemical

model. The profiles of N_2O_5 were measured for the first time at both sunrise (48°S) and sunset (28°N). The profiles are reported in ref. 6, except for the updated measurements of N_2O_5 which are in ref. 7.

Key Minor Gases. The ATMOS profiles of CH_4 , N_2O , CO , H_2O , and O_3 cover a wide region of the middle atmosphere (ref. 8). For example, the H_2O profiles extend from 14 to 86 km and the O_3 profiles cover 14 to 94 km. The ATMOS sunset profiles of CH_4 and N_2O show a fold in their vertical distributions which is probably the result of dynamics. The sunrise profiles do not show the fold. Recently, stratospheric profiles of the isotopic species H_2^{18}O , H_2^{17}O , HDO , and CH_3D have also been retrieved (ref. 9).

Other Gases. Profiles of the nonmethane hydrocarbons C_2H_6 and C_2H_2 (ref. 10) and the molecules HCN and OCS (ref. 11) have also been reported from the ATMOS/Spacelab 3 observations.

GROUND-BASED MEASUREMENTS OF TOTAL COLUMNS

High-resolution ($\sim 0.01\text{ cm}^{-1}$) solar absorption spectra recorded with the McMath Fourier transform spectrometer on Kitt Peak (altitude 2.09 km, 31.9°N , 111.6°W) have been analyzed to deduce total column amounts of HF on 93 different days and HCl on 35 different days between May 1977 and June 1990 (ref. 12). The results indicate a rapid increase in total HF and a more gradual increase in total HCl with both trends superimposed on a seasonal cycle with an early spring maximum and an early fall minimum. The peak-to-peak amplitudes of the seasonal cycle are equal to 25% for HF and 13% for HCl .

These results are of interest since current estimates indicate that the supersonic fleet may be operating in the early 21st century when the atmospheric concentrations of several key gases will be different than they are today. Sensitivity studies to assess the effects of these aircraft will necessarily require generating scenarios for future emissions including the projected emissions of supersonic and subsonic aircraft. The Kitt Peak measurements provide an opportunity to compare model calculations with a time series of accurate measurements for which there are fairly reliable data on emission histories and photo-oxidation rates for the source molecules. The model-predicted and measured total columns, increase rates, and seasonal cycles can be compared.

Of the two species, HF is better suited for the model-measurement comparisons because there probably are no significant tropospheric HF sources. In contrast, in the boundary layer, HCl is produced primarily by the interaction of SO_4 and NO_3 ions with NaCl in ocean spray, and to a lesser extent by surface anthropogenic emissions, such as the burning of plastics and emissions from certain industrial processes. Because of these sources, it is necessary to specify a nonzero surface level HCl flux in model calculations to simulate total column observations. Previous model-model comparisons showed large scatter in the calculated HCl total columns because of differences in the adopted surface level HCl concentration (ref. 13). Therefore, to

make meaningful comparisons with the Kitt Peak data, the tropospheric contribution will need to be prescribed in the model runs based on the observations, which indicate that the tropospheric contribution is about 15% of the total column.

Additional long-term IR spectroscopic observations of HF and HCl have been obtained from the Jungfraujoch station in the Switzerland (altitude 3.58 km, 46.5°N, 8.0°E). At the present time, R. Zander of the University of Liège and collaborators are reanalyzing the early data and extending the baseline of total column measurements based on recently collected solar spectra. It is unclear whether or not this updated database will be available in time for the upcoming HSRP model-measurement comparisons.

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This publication is in four volumes and represents the compilation of papers presented at the First Annual High-Speed Research Workshop held in Williamsburg, Virginia, on May 14-16, 1991. This NASA-sponsored workshop provided a national forum for presenting and discussing important technology issues related to the definition of an economically viable, and environmentally compatible High-Speed Civil Transport. The Workshop and this publication are organized into 13 sessions, with Session 1 presenting NASA and Industry overviews of the High-Speed Civil Transport Program. The remaining sessions are developed around the technical components of NASA's Phase I High-Speed Research Program, which addresses the environmental issues of atmospheric emissions, community noise and sonic boom. Because of the criticality of the materials and structures technology area, and the long-term nature of the supporting research requirements, a session was added in this area to capture the ongoing work at NASA Lewis and NASA Langley and within industry.

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